intel

Microprocessor and Peripheral Handbook

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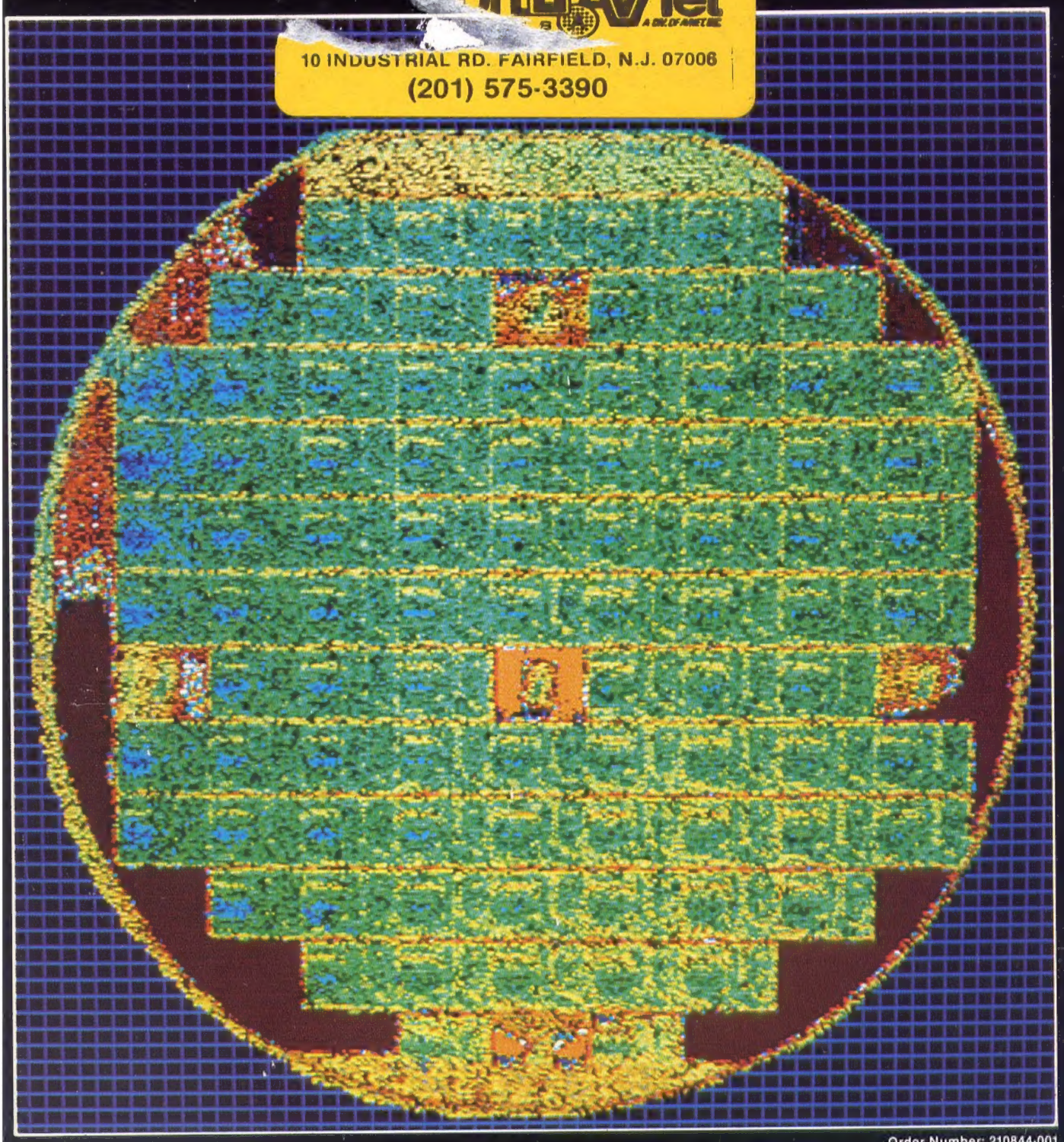

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AN ☐ Manufacturer of computers or peripheral equipment
AP ☐ Manufacturer of control equipment
AQ ☐ Manufacturer of test/measurement equipment or instruments
AR ☐ Manufacturer of communication/telecommunication equipment
AS ☐ Manufacturer of office/business equipment
AT ☐ System integration
AU ☐ User of computer equipment
AV ☐ Research lab/consultant
AW ☐ Software house
AX ☐ Government/military agency
AZ ☐ Sales office or distributor
AZ ☐ Other _____

3. Your company's/division's products fall primarily into:

BB ☐ Industrial **BC** ☐ Military **BD** ☐ Consumer

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BE ☐ Yes **BF** ☐ No

5. Are products that are purchased to your specifications incorporated into products to be sold or are they used in-house?

BG ☐ Incorporated into products to be sold **BJ** ☐ Both
BH ☐ Used in-house

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BK ☐ Distributor **BL** ☐ Manufacturer

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MICROPROCESSOR AND PERIPHERALS HANDBOOK

1983

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*Ethernet is a trademark of Xerox Corp.

General Information

1

QUALITY ASSURANCE OPERATIONS

QUALITY ASSURANCE OPERATIONS, CORPORATE POLICY

"It is the policy of Intel Corporation to design, manufacture, and deliver products that not only meet our specified standards, but also satisfy our customer standards, and perform reliably in their applications. To this end, Quality Assurance at Intel has the authority to exercise control of quality over every phase of the design and manufacturing process."

Intel Quality Program Policy,
Intel (Corporate) Policies and Procedures.

QUALITY ASSURANCE, THE SCOPE OF THE OPERATION

By definition, quality is conformance to specification . . . process or procedure, mechanical or electrical, customer or Intel. The operation chartered to maintain that conformance is "Quality Assurance." Within this operation, departmental activities include the day-to-day surveillance of manufacturing and testing of product, and the longer-range considerations of process, package, and product reliability. Just as quality is "conformance to specification," reliability is "continual conformance to specification." The reliability departments, process, package and product, play key roles in maintaining Intel's high quality standards, by being involved from concept to on-going production monitors throughout the product life.

ORGANIZATION, A UNIQUE MATRIX

All product-related Q.A. organizations come under a uniform policy, while still maintaining the flexibility to service the specific needs of a product area. To perform in this manner, a unique matrix organization was developed. All quality and reliability functions report directly through Q.A. operations or site managers to the Director of Quality Assurance. The flexibility is obtained by the Q.A. managers associated with product areas (such as E-PROMs, memories, microcontrollers, microprocessors and peripheral circuits) also reporting indirectly to (i.e., matrixing to) the operation or division general manager.

Additionally, each product area has both a quality and reliability group under a single Q.A. manager. This involvement on a product-specific level provides both the customer and Intel with the timely response necessary to maintain a problem-free product flow. And when there are problems, they are handled quickly on a local level. This results in a "team" approach, quality, reliability, development, manufacturing—making state-of-the-art technology available in a usable form for our customers.

RELIABILITY, DESIGNED-IN AND BUILT ON EXPERIENCE

Intel's extensive reliability program forms the basis of the quality program. Whether process, package or product, the appropriate reliability department is part of the development cycle from concept. In this way, the finished product is based on the reliability history of millions of devices—built on experience. To illustrate this philosophy, since 1970, the first application of a new technology has always been on a memory chip. This type of chip provides a large-volume basis to establish a reliability data base for the technology. As part of the data base, the memory device is extensively analyzed for failure mechanisms and the process technology altered to eliminate them. From this data base, under the guidance of process reliability, design rules, test patterns, and process limits evolve. Only after completing qualification will the technology be utilized in another type of device; such as a microprocessor. And so the data base grows, with more complex devices advancing the technology, each succeeding device being potentially more reliable than the last, because the devices are built on experience, and the reliability is designed-in.

The key to establishing a new product, process or package, or to changing an existing one, is the rigid qualification requirements which must be met. Qualification must be run and approved by the appropriate reliability department before any revenue shipment may be made. The reliability goals have been set during the concept stage in keeping with corporate objectives and must be demonstrated by the qualification. Consider one example, the qualification of a new wafer fab technology for E-PROMs. Below is a list of tests the first 5 wafer lots see during qualification:

125°C burn-in	168 hours
125°C lifetest	2000 hours
150°C HTRB	1000 hours
Low-temperature lifetest	1000 hours
250°C storage	1000 hours
Temperature cycle	−65°C to +150°C
Thermal shock	−65°C to +150°C
Test pattern study	
Program/erase cycling	
System verification	

It is from this type of sequence that infant mortality, random failure rates, and associated failure mechanisms are determined. Also from this data, reliability reports are written and made available to our customers.

While successful completion of qualification is the key to product introduction, it would be meaningless if the device was not sampled throughout its product life. As has been shown, the use of generic technology families evaluates the process each time a new product is qualified. More than that, on a rotating product basis, 125°C dynamic burn-in and lifetests are performed to continuously monitor all technologies. Fifty thousand devices each month are allocated for the Reliability Monitor Program by the Components Division. In this manner, all generic technology families are continuously scrutinized to assure that reliability goals are met.

In the same manner, Intel Package Reliability performs an extensive package monitor program to assure the mechanical integrity of every package type produced by every assembly facility.

QUALITY, THE DEVICE MEETS SPECIFICATION

The reliability program has been shown to support components quality through design-in, qualification, and on-going monitors. This forms the basis of the quality philosophy of looking at product from its concept, and requiring succeeding and more complex technologies/products to perform at levels better than those previous. The quality operations supporting this philosophy start, as reliability does, by working with the design team in the product concept stage.

Quality must approve the Target Specification for any new device. Later, before qualification, test programs are validated as meeting the required limits and conditions to guarantee operation of the product to specification.

The checks and balances implemented during the process flow start with incoming inspection of piece parts, wafers, chemicals and masks. All must meet the standards determined to be commensurate with Intel's product quality and reliability goals. The Materials Technology Laboratory plays a large support role in determining these standards, in some instances developing test methods where none exist to meet the complex control needs.

Throughout the entire process, an independent manufacturing group, Manufacturing Process Control, continuously monitors processes in wafer fabrication, assembly, die sort, burn-in and test areas. The group provides trend data and process auditing control on a day-to-day basis, involving quality and reliability groups when control problems are evident. In the case of wafer fabrication, the test methods and patterns used for process control by MPC have been designed by Process Reliability. In all areas, controls must be approved by Quality and Reliability.

Assembly Quality Assurance operates at all assembly sites instituting controls that guarantee product integrity irrespective of plant location. Consolidated trend data is published weekly, heading off potential problems by allowing effective concentration of engineering resources in a timely manner.

Final Quality Assurance (FQA) operates in each Test and Finish area to verify that Intel and customer requirements are met. Independent electrical sampling, external visual examination, and checking data requirements are some of the functions of this group.

Overlaying all areas is a network of calibration laboratories. Operating to Mil-Std-45662, the laboratory supports all operations by maintaining test and process equipment within their required tolerances. The group provides the baseline for all Intel measurements by both systems and bench-top equipment, assuring the validity of product shipments at the customer's location.

MAJOR PROGRAMS, CUSTOMER-ORIENTED TO PROVE AND IMPROVE QUALITY

Every area of quality and reliability at Intel has major programs which are customer-oriented. Several are detailed here to illustrate the manner in which Intel services the customer in the quality and reliability areas after the sale.

The Reliability Monitor Program, referred to in the "Reliability" section, is a burn-in and lifetest program which verifies that all of Intel's technologies are being controlled within specified reliability target goals. By utilizing a dynamic 125°C, 48-hour burn-in, "infant mortality" failure rates may be determined. A portion of these devices are continued to 1000 hours to determine random failure rates. This process technology-oriented data is now available to customers biannually to use instead of requiring product burn-in on a lot-by-lot basis.

There has been a need, that has grown with device complexity, for an Intel-customer correlation effort. This effort has resulted in the FACR (Failure Analysis Correlation Request) system within each division or operation. Operating through the Field Sales Engineers, the object of the program is to eliminate electrical test discrepancies between Intel and its customers in a timely manner. The system provides direct contact with a product-oriented Quality Engineer to eliminate test program or equipment discrepancies between the

customer and Intel without returning all product shipped. The success of the program may be measured by the numbers of lots that have been shipped to customers and been questioned and accepted after utilizing the FACR system. The obvious by-product of this system is to build customer confidence to the point where Intel's final test and FQA data becomes the customer's incoming inspection data.

The Military Quality Assurance program, operated out of the Phoenix site, attends to customers within the aerospace or military industry, or in some cases, to customers that have special documentation requirements. To perform in this product area, the Military Q.A. acts as an overlay on all sites and operations, defining the Q.A. program requirements in that particular area. The success of this program may be gauged by the acceptance of selected high-technology products by the Federal Government under Mil-M-38510, and the product processing areas certified by an agency of the Federal Government (see "Military Grade Products" for details). This department also performs process audits on a regular basis of applicable Intel manufacturing facilities to assure compliance to rigid military traceability and process requirements.

QUALITY ASSURANCE OPERATIONS FLOWCHART

The Quality Assurance Operations are involved in every phase of the Components Divisions. Activities vary from generating and validating design rules for a process technology to assuring the device count agrees with the Intel invoice in Plant Clearance. The following flowchart documents some of the major interactions of Quality and Reliability through the product lifecycle. Step-by-step inspection is not shown, but rather an overview of the entire cycle to illustrate the extent of Intel's commitment to provide the quality and reliability our customers have utilized since 1969.

QUALITY ASSURANCE OPERATIONS

PROCESS TECHNOLOGY

Reliability: Generate Design Rules
Generate Test Pattern
Process Qualification
Stress Testing
Failure Mode Analysis

PACKAGE TECHNOLOGY

Reliability: Process Qualification
Materials Test Methods
Materials Characterization

WAFER FABRI

Quality: Incoming Inspec
High Magnificati

Reliability: Process Qualific
Process Control,
Analytical Test L

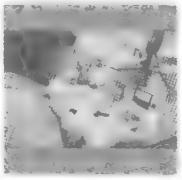
PRODUCT DESIGN

Quality: Parameter Limits, Testability
Test Program Control
Target Specification

PRODUCT VALIDATION/QUALIFICATION

Design Engineering: Design Verification
Design Engineering: Performance Verification
Applications Engineering: System Verification
Quality/Reliability: Qualification

ASSEMBLY



Quality: Incoming Inspection Gates
High/Low Magnification Visual Gates

Assembly Q.A. Acceptance

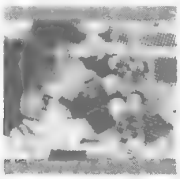
External Visual	Open/Short Test
Fine/Gross Leak®	Bond Pull
Centrifuge	Die Shear
Acoustic (PIND)	X-Ray
Mark Permanency	Internal Visual

Reliability: Process Qualification
Assembly Monitor Program

ate

lidation

ASSEMBLY MONITOR PROGRAM



External Visual	Internal Visual
Fine/Gross Leak®	Temperature Cycle
Lid Torque	Thermal Shock
Temp/Humidity℗	Steam
Moisture Resistance®	

TEST AND FINISH

Quality: Final Q.A. Acceptance

Electrical Test Sample	Physical Dimensions
Solderability	External Visual
Mark Permanency	Conformance to Sales Order

Reliability: Reliability Monitor Program

RELIABILITY MONITOR PROGRAM

48 Hr, 125°C Dynamic Burn-In
1000 Hr, 125°C Dynamic Lifetest

NOTES:

® Hermetic packages, only.

℗ Plastic packages, only.

PLANT CLEARANCE

Quality: External Visual
Sales Order Requirements

EXPRESS PROGRAM OVERVIEW

EXPRESS is a new service program that allows users of Intel IC components to tailor the products' electrical test flow to your specific application requirements. The test flows are designed to suit a broad range of system and production requirements.

The EXPRESS program offers users of Intel microcomputers, RAMs, EPROMs and peripheral component families, products that are screened to operate within two industry-standard temperature ranges, each with the option of 168±8 hours of dynamic burn (equivalent to MTR-STD-883B, Method 1015). All Intel processing technologies are included. New products will enter the program as they become available.

The key to using EXPRESS is the generic matrix. You can, by specifying a two-letter prefix, select the test flow your product requires including its operating temperature range and package type. The two operating temperature ranges are: Commercial (0°C to 70°C) and Extended (−40°C to 85°C). Products are available in both hermetic ceramic and molded plastic packages, that meet these temperature specifications. Adding the option of burn-in creates the versatile EXPRESS matrix.

	Burn-In Hours	
Temperature Range	**A (None)**	**B (168±8)**
I Commercial 0°C to 70°C	D,P	QD, QP
II Extended −40°C to 85°C	TD, TP	LD

EXPRESS Prefix Definitions

IA HIGH-QUALITY STANDARD PRODUCT

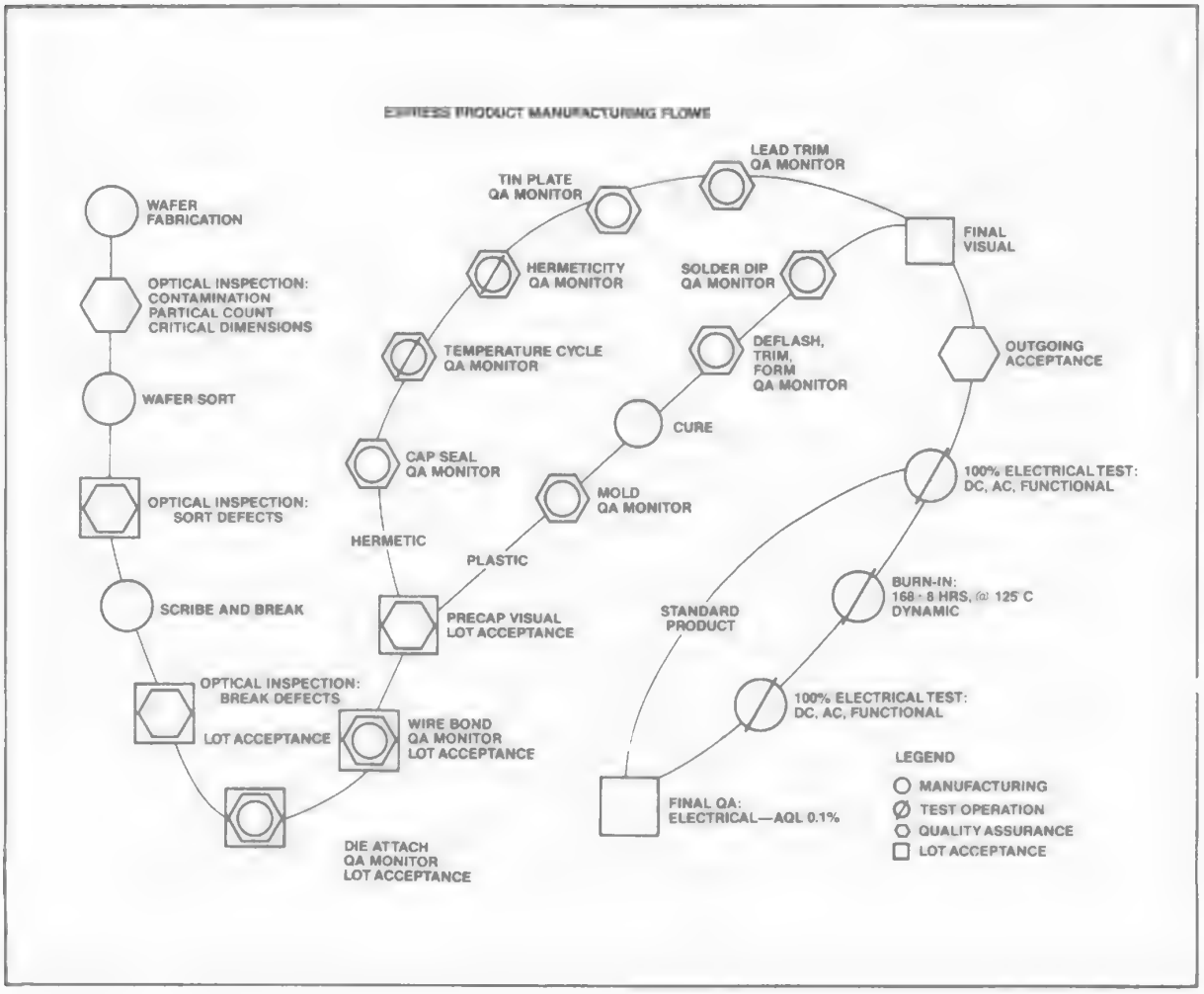
IB STANDARD PRODUCT WITH BURN-IN AND 100% UNIT POST BURN-IN ELECTRICAL SCREENING TO COMMERCIAL TEMPERATURE RANGE

IIA STANDARD PRODUCT WITH EXTENDED TEMPERATURE SCREENING

IIB STANDARD PRODUCT WITH BURN-IN AND 100% UNIT POST BURN-IN ELECTRICAL SCREENING TO EXTENDED TEMPERATURE RANGE

The EXPRESS test flow first subjects 100% of all products to a stringent class electrical examination. Complete DC, AC and functional parameters are tested at operating guard band temperature(s) for compliance to published specifications. Then, at your option, the product undergoes 168±8 hours of dynamic burn-in at 125°C. (By exercising the components' sequential circuitry while under burn-in stress, a more realistic emulation of the electrical operating environment is achieved.) Post burn-in screening features a 100% unit electrical retest of DC, AC and functional parameters to guarantee the product's performance over its designated operating temperature range.

Both these product flows, independent of package type, then receive sample screening for electrical and visual parameters by Final Quality Assurance to 0.1% AQL. This overall component sampling plan of 0.1% across the board, represents the tightest standard in the industry. These standards are periodically reviewed, and tightened according to Intel's Corporate quality goals.


EXPRESS PRODUCT MANUFACTURING FLOWS
WAFER FABRICATION
OPTICAL INSPECTION: CONTAMINATION PARTICAL COUNT CRITICAL DIMENSIONS
WAFER SORT
OPTICAL INSPECTION: SORT DEFECTS
SCRIBE AND BREAK
OPTICAL INSPECTION: BREAK DEFECTS
LOT ACCEPTANCE
DIE ATTACH QA MONITOR LOT ACCEPTANCE
WIRE BOND QA MONITOR LOT ACCEPTANCE
PRECAP VISUAL LOT ACCEPTANCE
HERMETIC
CAP SEAL QA MONITOR
TEMPERATURE CYCLE QA MONITOR
HERMETICITY QA MONITOR
TIN PLATE QA MONITOR
LEAD TRIM QA MONITOR
PLASTIC
MOLD QA MONITOR
CURE
DEFLASH, TRIM, FORM QA MONITOR
SOLDER DIP QA MONITOR
FINAL VISUAL
OUTGOING ACCEPTANCE
100% ELECTRICAL TEST: DC, AC, FUNCTIONAL
BURN-IN: 168 ± 8 HRS, @ 125°C DYNAMIC
100% ELECTRICAL TEST: DC, AC, FUNCTIONAL
STANDARD PRODUCT
FINAL QA: ELECTRICAL—AQL 0.1%
LEGEND
MANUFACTURING
TEST OPERATION
QUALITY ASSURANCE
LOT ACCEPTANCE

Intel Workshops

Training in Microcomputers

Whether your present involvement with microcomputers is a result of long-term planning or simply an exploratory project undertaken by your company in response to external circumstances, there exists an obvious and urgent need for you to familiarize yourself with this exciting new technology. If the microcomputer is, or is destined to become, a part of your working scene, then the importance of carefully planned training cannot be over-emphasized. A modest outlay in time and money now can save many weeks of self-study and could well prevent some very expensive mistakes during the initial development of your systems.

Why Intel Training?

EXPERIENCE
Intel has been training engineers in the application of microprocessors and the development of microcomputer systems since the early '70s, and there are now many thousands of engineers creating the most advanced microcomputer systems as a direct result of successful training with us.

VARIETY OF COURSES
Intel offers a wide spectrum of workshops covering all Intel microprocessor families from components to the board and system levels. Microcontroller and microprocessor workshops cover assembly language programming; high level languages are covered in separate intense courses. Your particular training requirement may involve just one or several courses, so we have taken care to ensure that each workshop is a high-quality training module that can either stand independently or integrate with other modules to completely cover the subject. The workshops are frequently updated to include the latest developments in devices, boards, software, and development tools, and reviewed on a regular basis for clarity and content.

PRODUCT KNOWLEDGE
As the designers and manufacturers of the most widely accepted microcomputer products in the world, our knowledge is both comprehensive and topical. Remember the saying about "the horse's mouth"!

EXTENSIVE MATERIAL
Teaching aids include slide and video tape equipment, student notebooks and a wide range of printed materials which are designed to provide post-training assimilation and act as practical reference manuals in your own laboratory.

"HANDS-ON" EXPERIENCE
We believe that students learn better by doing than by listening, so a sizeable proportion of course time is devoted to dynamic training via the INTELLEC development System, appropriate single-board computers, In-Circuit Emulators (ICE), I/O units for programming exercises, and computer kits for design and debugging sessions. Each student therefore receives valuable "hands-on" experience of the principles and techniques featured in the lecture sessions.

Accreditation for Workshops

Intel Customer Training offers Continuing Education Units (CEUs) for completion of our workshops. Attendees of our 5-day workshops receive 3.5 CEUs, while attendees of our 4-day and 3-day workshops receive 3.0 CEU and 2.0 CEUs respectively. Education Units provide recognition of professional growth and achievement.

AFN-01608C

Where Is Intel Training?

Workshops are presented in the local language.

Intel Customer Training is a worldwide organization with workshops scheduled nearly every week of the year in our training centers:

BOSTON AREA
(617) 256-1374
TWX 710-343-6333

CHICAGO AREA
(312) 981-7250
TWX 910-651-5881

DALLAS AREA
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TWX 910-860-5617

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Telex 19567

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(972) 452-4261
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AFN-01608C

MCS®-80/85 Microprocessors

Course Description

- 8085 architecture explained in detail
- Assembly language programming for 8080/8085
- Design and development of systems using Intel 8080, 8085 chips
- Interfacing and programming techniques
- "Hands-on" lab sessions using the Intellec Microcomputer Development System
- ICE-85 In-Circuit Emulator used to debug programs

Attendees

- Design engineer or programmer who is familiar with binary numbers and logic functions
- Prior attendance at Introduction to Microcomputers Workshop or equivalent knowledge is recommended

Length: 5 Days

Tuition: $995
$850 (Group rate)

Course Outline

DAY 1

Introduction to Microprocessors
Assembly Language Instructions
Programmed Input and Output
Microcomputer Development System Monitor
Lab: Using System Monitor

DAY 2

Microcomputer Development System
Disk Operating System
CREDIT Text Editor and Macro Assembler
The Processors
Lab: Using Text Editor and Assembler

DAY 3

Stacks and Subroutines
Interrupts
In-Circuit Emulator
Lab: In-Circuit Emulator Introduction

DAY 4

Input and Output Techniques
Programming Techniques
Lab: Using 8085 In-Circuit Emulator

DAY 5

8555, 8355, 8185, 8251A Peripherals
Tools for Modular Program Development
Lab: Multimodule Programming

AFN-01608C

iAPX 86,88,186 Microprocessors Part I

Course Description

- Programming with ASM 86.
- Lectures cover CPU, interrupts, timing, and I/O
- Designing iAPX 86,88,186-based systems
- "Hands-on" laboratory uses INTELLEC development system and DEBUG-86

Attendees

- Design engineer or programmer who will use or evaluate iAPX 86,88,186 products
- Digital circuit experience and familiarity with binary numbers is required
- Prior attendance to Introduction to Microcomputers Workshop or equivalent experience is highly recommended

Length: 5 Days

Tuition: $995
$850 (Group rate)

Course Outline

DAY 1

Introduction to Microcomputers
iAPX 86,88,186 Programming Model
Assembly Language Instructions
Lab: Using ALTER and Assembler

DAY 2

iAPX 86,88,186 CPU sets
System Design and Timing
Accessing Data
DEBUG-86
Lab: Testing and Debugging programs with DEBUG-86

DAY 3

Procedures
iAPX 86,88 Interrupt System
Memory and I/O Interfacing
Lab: Programming with Procedures

DAY 4

Multi-Segment Programming
Enhancements to the iAPX 186 CPU
iAPX 186 Interrupt System
iAPX 186 Chip Select/Wait State Logic
Lab: Programming with Multiple Segments

DAY 5

iAPX 186 Timer
iAPX 186 DMA Controller
Modular Programming
Lab: Programming with Multiple Modules

AFN-01608C

iAPX 86,88,186 Microprocessors Part II

Length: 5 Days

Tuition: $995
$850 (Group rate)

Course Description

- Programming of large systems based on the iAPX 86,88,186 family of products
- Efficient programming using segmentation
- Detailed explanation of addressing modes
- Detailed usage of the iAPX 86 programming utilities (LINK86, LOC86, LIB86)
- Linking assembly language with high level languages (PL/M, Pascal, FORTRAN)
- Detailed discussion of the 8087 Numeric Processor Extension
- Introduction to the 8089 I/O Processor
- "Hands-on" laboratory uses INTELLEC Microcomputer Development System and DEBUG-86

Attendees

- Design engineer or programmer who needs an advanced understanding of the iAPX 86,88,186 product line.
- Knowledge of the INTELLEC Development System required.
- Prior attendance at the iAPX 86, 88,186 Microprocessor Workshop, Part I is recommended. However, experienced design engineers or programmers who are already familiar with the iAPX 86,88,186 architecture and instruction set may attend this more advanced workshop.

Course Outline

DAY 1

iAPX 86,88,186 Architecture and Instruction Set Review
Segmentation
Overview of the software development process
Lab: Writing multiple segment program

DAY 2

Accessing data memory
String operators
Modular program development
LINK86,LOC86,LIB86
Lab: Using string operators Programming with multiple modules

DAY 3

Data Structures
Based Addressing
Linkage with PL/M
Lab: Using Data Structures Linking with PL/M

DAY 4

Linkage with Pascal and FORTRAN
Introduction to the 8087 numeric processor extension
8087 register stack
8087 instruction set
Lab: Using the 8087 NPX

DAY 5

Multibus system design
Introduction to the 8089 I/O processor
Lab: More on the 8087.

AFN-01608C

iAPX 286 Architecture

Course Description

- Describes operating modes of the iAPX 286 microprocessor
- Explains the protection model of the iAPX 286 and its hardware implementation
- Discusses the instruction set of the iAPX 286 including the memory management and protection support instructions
- Covers the iAPX 86,88 and iAPX 286 interprocessor compatibility issues
- "Hands-on" lab sessions using the iAPX 286 Evaluation Package and Series III Development System

Attendees

- Engineer or systems programmers interested in using or evaluating the iAPX 286 microprocessor
- Knowledge of iAPX 86,88 architecture assumed
- Knowledge of Development System operation required
- Familiarity with operating system internals is recommended

Length: 3 Days

Tuition: $650
$550 (Group rate)

Course Outline

DAY 1

iAPX 286 Operating Modes
iAPX 86/iAPX 286 Comparison
Privilege Levels
Task State Switching
iAPX 286 Evaluation Package and Simulator Software
Lab: Using the Simulator

DAY 2

Memory Management
Protection
Fault Recovery
Virtual Memory
Evaluation Builder Software
Lab: Using Evaluation Builder

DAY 3

Hardware Design
Multibus Interfacing
Numeric Data Processor
System Initialization

AFN-01608C

Peripheral Chips (Emphasizing Data Communications)

Course Description

- Explains and demonstrates use of asynchronous, byte synchronous, bit synchronous and local network serial communications, including Ethernet*
- Explains how to utilize Intel chips effectively and avoid problems
- Discusses data transmission via telephone lines

Attendees

- Intended for the design engineer, service engineer or programmer who wants to learn serial communciation techniques and implement them using state-of-the-art microcomputer products
- Prior attendance to iAPX 86 Workshop is required

Length: 4 Days

Tuition: $795
$675 (Group rate)

Course Outline

DAY 1

- The History of Data Communications
- Asynchronous Communication
- Description and Use of:
  - 8251A USART
  - 8253/8254 Programmable Timer
  - 8274 Multi-Protocol Serial Controller
- Lab: Asynchronous Communications

DAY 2

- Byte Synchronous Communication
- Modems (Modulators/Demodulators)
- RS-232, RS-422
- iSBC 88/45 Communications Board
- Use of 8237 DMA Controller and Use of 8259A Interrupt Controller
- iSBX 351 Communications Board
- Lab: Bi-synchronous Communication

DAY 3

- Bit Synchronous Communication
- SDLC/HDLC Communication
- Description and Use of 8273 SDLC Protocol Controller
- Lab: SDLC Loop Using the 8273

DAY 4

- Layered Communications
- Ethernet Local Area Network

*Ethernet is a trademark of Xerox Corporation.

AFN-01608C

Data Comm/Ethernet

MCS®-80/85 Microprocessors

2

8080A/8080A-1/8080A-2
8-BIT N-CHANNEL MICROPROCESSOR

- **TTL Drive Capability**
- **2 μs (−1:1.3 μs, −2:1.5 μs) Instruction Cycle**
- **Powerful Problem Solving Instruction Set**
- **6 General Purpose Registers and an Accumulator**
- **16-Bit Program Counter for Directly Addressing up to 64K Bytes of Memory**
- **16-Bit Stack Pointer and Stack Manipulation Instructions for Rapid Switching of the Program Environment**
- **Decimal, Binary, and Double Precision Arithmetic**
- **Ability to Provide Priority Vectored Interrupts**
- **512 Directly Addressed I/O Ports**
- **Available in EXPRESS**
  - Standard Temperature Range

The Intel® 8080A is a complete 8-bit parallel central processing unit (CPU). It is fabricated on a single LSI chip using Intel's n-channel silicon gate MOS process. This offers the user a high performance solution to control and processing applications.

The 8080A contains 6 8-bit general purpose working registers and an accumulator. The 6 general purpose registers may be addressed individually or in pairs providing both single and double precision operators. Arithmetic and logical instructions set or reset 4 testable flags. A fifth flag provides decimal arithmetic operation.

The 8080A has an external stack feature wherein any portion of memory may be used as a last in/first out stack to store/retrieve the contents of the accumulator, flags, program counter, and all of the 6 general purpose registers. The 16-bit stack pointer controls the addressing of this external stack. This stack gives the 8080A the ability to easily handle multiple level priority interrupts by rapidly storing and restoring processor status. It also provides almost unlimited subroutine nesting.

This microprocessor has been designed to simplify systems design. Separate 16-line address and 8-line bidirectional data busses are used to facilitate easy interface to memory and I/O. Signals to control the interface to memory and I/O are provided directly by the 8080A. Ultimate control of the address and data busses resides with the HOLD signal. It provides the ability to suspend processor operation and force the address and data busses into a high impedance state. This permits OR-tying these busses with other controlling devices for (DMA) direct memory access or multi-processor operation.

NOTE:
The 8080A is functionally and electrically compatible with the Intel® 8080.

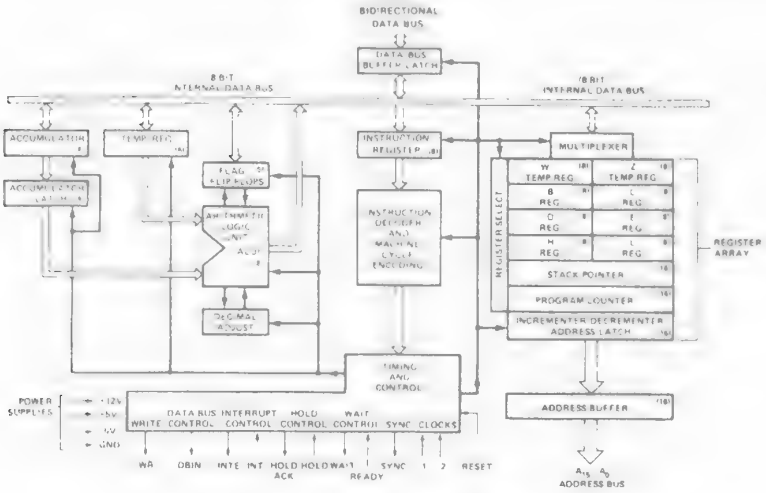


Figure 1. Block Diagram

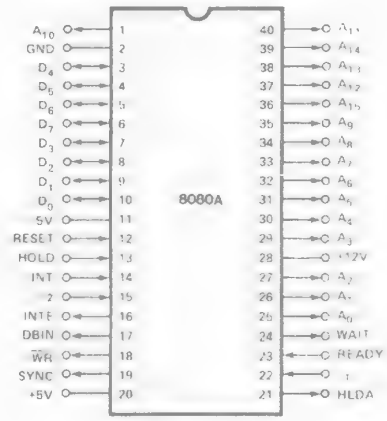


Figure 2. Pin Configuration

Table 1. Pin Description

Symbol	Type	Name and Function
A_{15}-A_0	O	**Address Bus:** The address bus provides the address to memory (up to 64K 8-bit words) or denotes the I/O device number for up to 256 input and 256 output devices. A_0 is the least significant address bit.
D_7-D_0	I/O	**Data Bus:** The data bus provides bi-directional communication betweeen the CPU, memory, and I/O devices for instructions and data transfers. Also, during the first clock cycle of each machine cycle, the 8080A outputs a status word on the data bus that describes the current machine cycle. D_0 is the least significant bit.
SYNC	O	**Synchronizing Signal:** The SYNC pin provides a signal to indicate the beginning of each machine cycle.
DBIN	O	**Data Bus In:** The DBIN signal indicates to external circuits that the data bus is in the input mode. This signal should be used to enable the gating of data onto the 8080A data bus from memory or I/O.
READY	I	**Ready:** The READY signal indicates to the 8080A that valid memory or input data is available on the 8080A data bus. This signal is used to synchronize the CPU with slower memory or I/O devices. If after sending an address out the 8080A does not receive a READY input, the 8080A will enter a WAIT state for as long as the READY line is low. READY can also be used to single step the CPU.
WAIT	O	**Wait:** The WAIT signal acknowledges that the CPU is in a WAIT state.
$\overline{WR}$	O	**Write:** The $\overline{WR}$ signal is used for memory WRITE or I/O output control. The data on the data bus is stable while the $\overline{WR}$ signal is active low ($\overline{WR}$ = 0).
HOLD	I	**Hold:** The HOLD signal requests the CPU to enter the HOLD state. The HOLD state allows an external device to gain control of the 8080A address and data bus as soon as the 8080A has completed its use of these busses for the current machine cycle. It is recognized under the following conditions: • the CPU is in the HALT state. • the CPU is in the T2 or TW state and the READY signal is active. As a result of entering the HOLD state the CPU ADDRESS BUS (A_{15}-A_0) and DATA BUS (D_7-D_0) will be in their high impedance state. The CPU acknowledges its state with the HOLD ACKNOWLEDGE (HLDA) pin.
HLDA	O	**Hold Acknowledge:** The HLDA signal appears in response to the HOLD signal and indicates that the data and address bus will go to the high impedance state. The HLDA signal begins at: • T3 for READ memory or input • The Clock Period following T3 for WRITE memory or OUTPUT operation In either case, the HLDA signal appears after the rising edge of ϕ_2.
INTE	O	**Interrupt Enable:** Indicates the content of the internal interrupt enable flip/flop. This flip/flop may be set or reset by the Enable and Disable Interrupt instructions and inhibits interrupts from being accepted by the CPU when it is reset. It is automatically reset (disabling further interrupts) at time T1 of the instruction fetch cycle (M1) when an interrupt is accepted and is also reset by the RESET signal.
INT	I	**Interrupt Request:** The CPU recognizes an interrupt request on this line at the end of the current instruction or while halted. If the CPU is in the HOLD state or if the Interrupt Enable flip/flop is reset it will not honor the request.
RESET[1]	I	**Reset:** While the RESET signal is activated, the content of the program counter is cleared. After RESET, the program will start at location 0 in memory. The INTE and HLDA flip/flops are also reset. Note that the flags, accumulator, stack pointer, and registers are not cleared
V_{SS}		**Ground:** Reference.
V_{DD}		**Power:** +12 ±5% Volts.
V_{CC}		**Power:** +5 ±5% Volts.
V_{BB}		**Power:** −5 ±5% Volts.
ϕ_1, ϕ_2		**Clock Phases:** 2 externally supplied clock phases. (non TTL compatible)

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias . . . . . 0°C to +70° C
Storage Temperature . . . . . -65°C to +150°C
All Input or Output Voltages
With Respect to V_{BB} . . . . . -0.3V to +20V
V_{CC}, V_{DD} and V_{SS} With Respect to V_{BB} -0.3V to +20V
Power Dissipation 1.5W

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{DD} = +12V ±5%, V_{CC} = +5V ±5%, V_{BB} = −5V ±5%, V_{SS} =0V; unless otherwise noted)

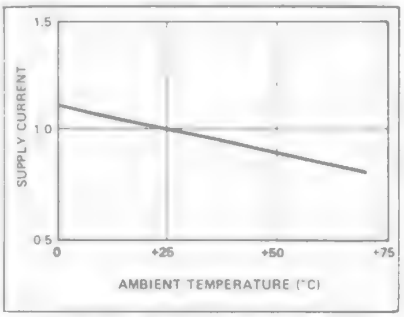
Symbol	Parameter	Min.	Typ.	Max.	Unit	Test Condition
V_{ILC}	Clock Input Low Voltage	V_{SS} −1		V_{SS}+0.8	V	
V_{IHC}	Clock Input High Voltage	9.0		V_{DD}+1	V	
V_{IL}	Input Low Voltage	V_{SS} −1		V_{SS}+0.8	V	
V_{IH}	Input High Voltage	3.3		V_{CC}+1	V	
V_{OL}	Output Low Voltage			0.45	V	I_{OL} = 1.9mA on all outputs, I_{OH} = −150μA.
V_{OH}	Output High Voltage	3.7			V	
$I_{DD(AV)}$	Avg. Power Supply Current (V_{DD})		40	70	mA	Operation T_{CY} = .48 μsec
$I_{CC(AV)}$	Avg. Power Supply Current (V_{CC})		60	80	mA	
$I_{BB(AV)}$	Avg. Power Supply Current (V_{BB})		.01	1	mA	
I_{IL}	Input Leakage			±10	μA	$V_{SS} \leq V_{IN} \leq V_{CC}$
I_{CL}	Clock Leakage			±10	μA	$V_{SS} \leq V_{CLOCK} \leq V_{DD}$
I_{DL} [2]	Data Bus Leakage in Input Mode			-100 -2.0	μA mA	$V_{SS} \leq V_{IN} \leq V_{SS}$+0.8V V_{SS}+0.8V$\leq V_{IN} \leq V_{CC}$
I_{FL}	Address and Data Bus Leakage During HOLD			+10 -100	μA	$V_{ADDR/DATA} = V_{CC}$ $V_{ADDR/DATA} = V_{SS}$ + 0.45V

CAPACITANCE (T_A = 25°C, V_{CC} = V_{DD} =V_{SS} = 0V, V_{BB} = −5V)

Symbol	Parameter	Typ.	Max.	Unit	Test Condition
C_ϕ	Clock Capacitance	17	25	pf	f_c = 1 MHz
C_{IN}	Input Capacitance	6	10	pf	Unmeasured Pins
C_{OUT}	Output Capacitance	10	20	pf	Returned to V_{SS}

NOTES:

1. The RESET signal must be active for a minimum of 3 clock cycles.
2. ΔI supply / ΔT_A = −0.45%/°C.



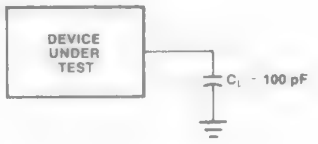
Typical Supply Current vs. Temperature, Normalized[3]

A.C. CHARACTERISTICS (8080A)

(T_A = 0°C to 70°C, V_{DD} = +12V ±5%, V_{CC} = +5V ±5%, V_{BB} = −5V ±5%, V_{SS} = 0V; unless otherwise noted)

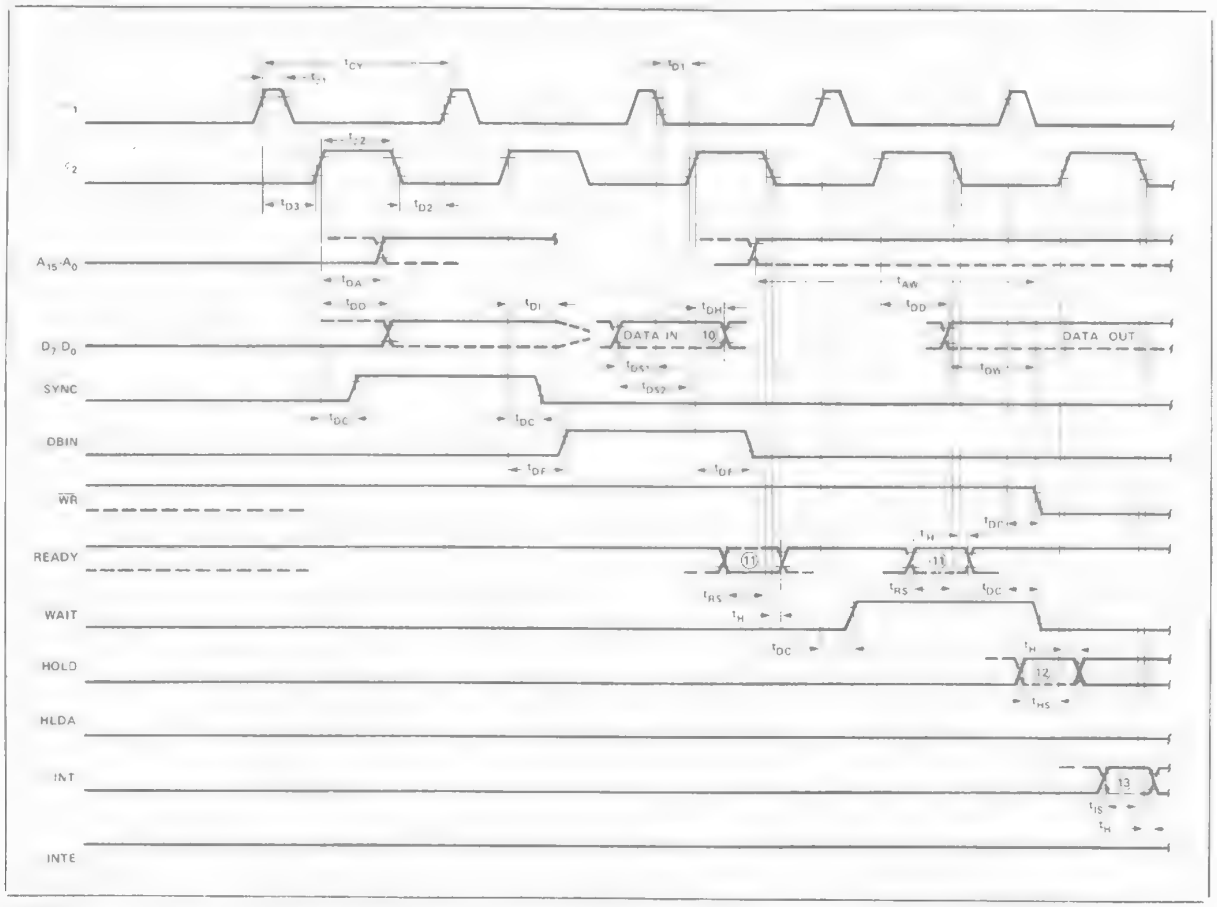
Symbol	Parameter	Min.	Max.	-1 Min.	-1 Max.	-2 Min.	-2 Max.	Unit	Test Condition
t_{CY}[3]	Clock Period	[illegible]	2.0	0.32	2.0	0.38	2.0	μsec	
t_r, t_f	Clock Rise and Fall Time	0	50	0	25	0	50	nsec	
$t_{\phi 1}$	ϕ_1 Pulse Width	60		50		[illegible]		nsec	
$t_{\phi 2}$	ϕ_2 Pulse Width	220		145		175		[illegible]	
t_{D1}	Delay ϕ_1 to ϕ_2	0		0		0		[illegible]	
t_{D2}	Delay ϕ_2 to ϕ_1	70		60		70		nsec	
t_{D3}	Delay ϕ_1 to ϕ_2 Leading Edges	[illegible]		[illegible]		[illegible]		nsec	
t_{DA}	Address Output Delay From ϕ_2		200		[illegible]		175	[illegible]	C_L = 100 pF
t_{DD}	Data Output Delay From ϕ_2		220		180		200	[illegible]	C_L = 100 pF
t_{DC}	Signal Output Delay From ϕ_2 or ϕ_2 (SYNC, WR, WAIT, HLDA)		120		110		120	[illegible]	C_L = 50 pF
t_{DF}	DBIN Delay From ϕ_2	25	140	25	130	25	140	nsec	C_L = 50 pF
t_{DI}[1]	Delay for Input Bus to Enter Input Mode		t_{DF}		t_{DF}		t_{DF}	[illegible]	
t_{DS1}	Data Setup Time During ϕ_1 and DBIN	[illegible]		10		20		nsec	
t_{DS2}	Data Setup Time to ϕ_2 During DBIN	150		[illegible]		130		[illegible]	
t_{DH}[1]	Data Holt time From ϕ_2 During DBIN	[1]		[1]		[1]		nsec	
t_{IE}	INTE Output Delay From ϕ_2		200		200		[illegible]	[illegible]	C_L = 50 pF
t_{RS}	READY Setup Time During ϕ_2	120		[illegible]		[illegible]		[illegible]	
t_{HS}	HOLD Setup Time to ϕ_2	140		120		120		[illegible]	
t_{IS}	INT Setup Time During ϕ_2	120		100		100		[illegible]	
t_H	Hold Time From ϕ_2 (READY, INT, HOLD)	0		0		0		[illegible]	
t_{FD}	Delay to Float During Hold (Address and Data Bus)		120		120		120	nsec	
t_{AW}	Address Stable Prior to WR	[5]		[5]		[5]		[illegible]	C_L = 100 pF: Address, Data; C_L = 50 pF: $\overline{WR}$, HLDA, DBIN
t_{DW}	Output Data Stable Prior to WR	[illegible]		[illegible]		[6]		nsec	C_L = 100 pF: Address, Data; C_L = 50 pF: $\overline{WR}$, HLDA, DBIN
t_{WD}	Output Data Stable From WR	[7]		[7]		[7]		nsec	C_L = 100 pF: Address, Data; C_L = 50 pF: $\overline{WR}$, HLDA, DBIN
t_{WA}	Address Stable From WR	[7]		[7]		[7]		nsec	C_L = 100 pF: Address, Data; C_L = 50 pF: $\overline{WR}$, HLDA, DBIN
t_{HF}	HLDA to Float Delay	[8]		[8]		[8]		nsec	C_L = 100 pF: Address, Data; C_L = 50 pF: $\overline{WR}$, HLDA, DBIN
t_{WF}	WR to Float Delay	[9]		[illegible]		[9]		nsec	C_L = 100 pF: Address, Data; C_L = 50 pF: $\overline{WR}$, HLDA, DBIN
t_{AH}	Address Hold Time After DBIN During HLDA	−20		−20		−20		nsec	C_L = 100 pF: Address, Data; C_L = 50 pF: $\overline{WR}$, HLDA, DBIN

A.C. TESTING LOAD CIRCUIT



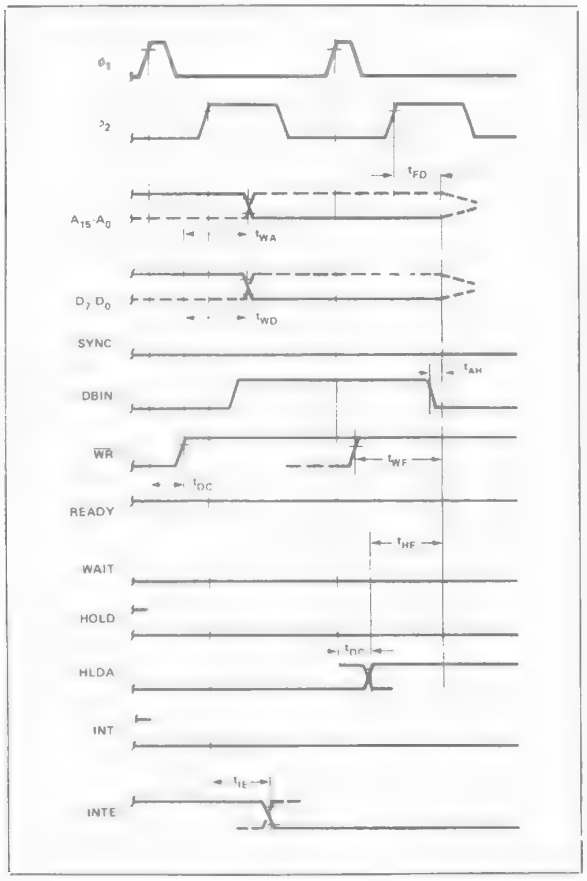
C_L = 100 pF
C_L INCLUDES JIG CAPACITANCE

WAVEFORMS



NOTE:
Timing measurements are made at the following reference voltages: CLOCK "1" = 8.0V, "0" = 1.0V; INPUTS "1" = 3.3V, "0" = 0.8V; OUTPUTS "1" = 2.0V, "0" = 0.8V.

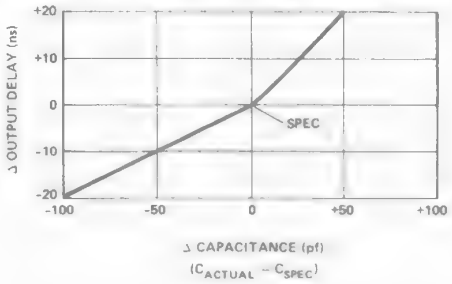
WAVEFORMS (Continued)



NOTES: (Parenthesis gives -1, -2 specifications, respectively)

1. Data input should be enabled with DBIN status. No bus conflict can then occur and data hold time is assured. t_{DH} = 50 ns or t_{DF}, whichever is less.
2. $t_{CY} = t_{D3} + t_{r\phi 2} + t_{\phi 2} + t_{f\phi 2} + t_{D2} + t_{r\phi 1} \geq 480$ ns (− 1:320 ns, − 2:380 ns).

TYPICAL Δ OUTPUT DELAY VS. Δ CAPACITANCE



3. The following are relevant when interfacing the 8080A to devices having V_{IH} = 3.3V:
   a) Maximum output rise time from .8V to 3.3V = 100ns @ C_L = SPEC.
   b) Output delay when measured to 3.0V = SPEC +60ns @ C_L = SPEC.
   c) If C_L = SPEC, add .6ns/pF if $C_L > C_{SPEC}$, subtract .3ns/pF (from modified delay) if $C_L < C_{SPEC}$.
4. $t_{AW} = 2\,t_{CY} - t_{D3} - t_{r\phi 2} - 140$ ns (− 1:110 ns, − 2:130 ns).
5. $t_{DW} = t_{CY} - t_{D3} - t_{r\phi 2} - 170$ ns (− 1:150 ns, − 2:170 ns).
6. If not HLDA, $t_{WD} = t_{WA} = t_{D3} + t_{r\phi 2} + 10$ ns. If HLDA, $t_{WD} = t_{WA} = t_{WF}$.
7. $t_{HF} = t_{D3} + t_{r\phi 2} - 50$ ns).
8. $t_{WF} = t_{D3} + t_{r\phi 2} - 10$ns.
9. Data in must be stable for this period during DBIN T_3. Both t_{DS1} and t_{DS2} must be satisfied.
10. Ready signal must be stable for this period during T_2 or T_W. (Must be externally synchronized.)
11. Hold signal must be stable for this period during T_2 or T_W when entering hold mode, and during T_3, T_4, T_5 and T_{WH} when in hold mode. (External synchronization is not required.)
12. Interrupt signal must be stable during this period of the last clock cycle of any instruction in order to be recognized on the following instruction. (External synchronization is not required.)
13. This timing diagram shows timing relationships only; it does not represent any specific machine cycle.

INSTRUCTION SET

The accumulator group instructions include arithmetic and logical operators with direct, indirect, and immediate addressing modes.

Move, load, and store instruction groups provide the ability to move either 8 or 16 bits of data between memory, the six working registers and the accumulator using direct, indirect, and immediate addressing modes.

The ability to branch to different portions of the program is provided with jump, jump conditional, and computed jumps. Also the ability to call to and return from subroutines is provided both conditionally and unconditionally. The RESTART (or single byte call instruction) is useful for interrupt vector operation.

Double precision operators such as stack manipulation and double add instructions extend both the arithmetic and interrupt handling capability of the 8080A. The ability to increment and decrement memory, the six general registers and the accumulator is provided as well as extended increment and decrement instructions to operate on the register pairs and stack pointer. Further capability is provided by the ability to rotate the accumulator left or right through or around the carry bit.

Input and output may be accomplished using memory addresses as I/O ports or the directly addressed I/O provided for in the 8080A instruction set.

The following special instruction group completes the 8080A instruction set: the NOP instruction, HALT to stop processor execution and the DAA instructions provide decimal arithmetic capability. STC allows the carry flag to be directly set, and the CMC instruction allows it to be complemented. CMA complements the contents of the accumulator and XCHG exchanges the contents of two 16-bit register pairs directly.

Data and Instruction Formats

Data in the 8080A is stored in the form of 8-bit binary integers. All data transfers to the system data bus will be in the same format.

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0

DATA WORD

The program instructions may be one, two, or three bytes in length. Multiple byte instructions must be stored in successive words in program memory. The instruction formats then depend on the particular operation executed.

One Byte Instructions

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	OP CODE

TYPICAL INSTRUCTIONS

Register to register, memory reference, arithmetic or logical, rotate, return, push, pop, enable or disable Interrupt instructions

Two Byte Instructions

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	OP CODE
D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	OPERAND

Immediate mode or I/O instructions

Three Byte Instructions

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	OP CODE
D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	LOW ADDRESS OR OPERAND 1
D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	HIGH ADDRESS OR OPERAND 2

Jump, call or direct load and store instructions

For the 8080A a logic "1" is defined as a high level and a logic "0" is defined as a low level.

Table 2. Instruction Set Summary

Mnemonic	Instruction Code [1] D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Operations Description	Clock Cycles [2]
MOVE, LOAD, AND STORE										
MOVr1,r2	0	1	[illegible]	D	D	S	[illegible]	S	Move register to register	[illegible]
MOV M,r	0	1	1	1	0	S	S	[illegible]	Move register to memory	7
MOV r,M	0	1	[illegible]	[illegible]	[illegible]	1	1	0	Move memory to register	7
MVI r	0	0	D	D	[illegible]	1	1	0	Move immediate register	7
MVI M	0	0	1	1	0	1	1	0	Move immediate memory	10
LXI B	0	0	0	0	0	0	0	1	Load immediate register Pair B & C	10
LXI D	0	0	0	1	0	0	0	1	Load immediate register Pair D & E	10
LXI H	0	0	1	0	0	0	0	1	Load immediate register Pair H & L	10
STAX B	0	0	0	0	0	0	1	0	Store A indirect	7
STAX D	0	0	0	1	0	0	1	0	Store A indirect	7
LDAX B	0	0	0	0	1	0	1	0	Load A indirect	7
LDAX D	0	0	0	1	1	0	1	0	Load A indirect	7
STA	0	0	1	1	0	0	1	0	Store A direct	13
LDA	0	0	1	1	1	0	1	0	Load A direct	13
SHLD	0	0	1	0	0	0	1	0	Store H & L direct	16
LHLD	0	0	1	0	1	0	1	0	Load H & L direct	16
XCHG	1	1	1	0	1	0	1	1	Exchange D & E, H & L Registers	[illegible]
STACK OPS										
PUSH B	1	1	0	0	0	1	0	1	Push register Pair B & C on stack	11
PUSH D	1	1	0	1	0	1	0	1	Push register Pair D & E on stack	11
PUSH H	1	1	1	0	0	1	0	1	Push register Pair H & L on stack	11
PUSH PSW	1	1	1	1	0	1	0	1	Push A and Flags on stack	11
POP B	1	1	0	0	0	0	0	1	Pop register Pair B & C off stack	10
POP D	1	1	0	1	0	0	0	1	Pop register Pair D & E off stack	10
POP H	1	1	1	0	0	0	0	1	Pop register Pair H & L off stack	10
POP PSW	1	1	1	1	0	0	0	1	Pop A and Flags off stack	10
XTHL	1	1	1	0	0	0	1	1	Exchange top of stack, H & L	18
SPHL	1	1	1	1	1	0	0	1	H & L to stack pointer	5
LXI SP	0	0	1	1	0	0	0	1	Load immediate stack pointer	10
INX SP	0	0	1	1	0	0	1	1	Increment stack pointer	[illegible]
DCX SP	0	0	1	1	1	0	1	1	Decrement stack pointer	5
JUMP										
JMP	1	1	0	0	0	0	1	1	Jump unconditional	10
JC	1	1	0	1	1	0	1	0	Jump on carry	10
JNC	1	1	0	1	0	0	1	0	Jump on no carry	10
JZ	1	1	0	0	1	0	1	0	Jump on zero	10
JNZ	1	1	0	0	0	0	1	0	Jump on no zero	10
JP	1	1	1	1	0	0	1	0	Jump on positive	10
JM	1	1	1	1	1	0	1	0	Jump on minus	10
JPE	1	1	1	0	1	0	1	0	Jump on parity even	10
JPO	1	1	1	0	0	0	1	0	Jump on parity odd	10
PCHL	1	1	1	0	1	0	0	1	H & L to program counter	5
CALL										
CALL	1	1	0	0	1	1	0	1	Call unconditional	17
CC	1	1	0	1	1	1	0	0	Call on carry	11/17
CNC	1	1	0	1	0	1	0	0	Call on no carry	11/17
CZ	1	1	0	0	1	1	0	0	Call on zero	11/17
CNZ	1	1	0	0	0	1	0	0	Call on no zero	11/17
CP	1	1	1	1	0	1	0	0	Call on positive	11/17
CM	[illegible]	1	1	1	1	1	0	0	Call on minus	11/17
CPE	1	1	1	0	1	1	0	0	Call on parity even	11/17
CPO	1	1	1	0	0	1	0	0	Call on parity odd	11/17
RETURN										
RET	1	1	0	0	1	0	0	1	Return	10
RC	1	1	0	1	1	0	0	0	Return on carry	5/11
RNC	1	1	0	1	0	0	0	0	Return on no carry	5/11
RZ	1	1	0	0	1	0	0	0	Return on zero	5/11
RNZ	1	1	0	0	0	0	0	0	Return on no zero	5/11
RP	1	1	1	1	0	0	0	0	Return on positive	5/11
RM	1	1	1	1	1	0	0	0	Return on minus	5/11
RPE	1	1	1	0	1	0	0	0	Return on parity even	5/11
RPO	1	1	1	0	0	0	0	0	Return on parity odd	5/11
RESTART										
RST	1	1	A	A	A	1	1	1	Restart	11
INCREMENT AND DECREMENT										
INR r	0	0	D	D	D	1	0	0	Increment register	5
DCR r	0	0	D	D	D	1	0	1	Decrement register	[illegible]
INR M	0	0	1	1	0	1	0	0	Increment memory	10
DCR M	0	0	1	1	0	1	0	1	Decrement memory	10
INX B	0	0	0	0	0	0	1	1	Increment B & C registers	[illegible]
INX D	0	0	0	1	0	0	1	1	Increment D & E registers	5
INX H	0	0	1	0	0	0	1	1	Increment H & L registers	[illegible]
DCX B	0	0	0	0	1	0	1	1	Decrement B & C	5
DCX D	0	0	0	1	1	0	1	1	Decrement D & E	5
DCX H	0	0	1	0	1	0	1	1	Decrement H & L	[illegible]
ADD										
ADD r	[illegible]	0	0	0	0	S	S	S	Add register to A	4
ADC r	[illegible]	0	0	0	1	S	S	[illegible]	Add register to A with carry	4
ADD M	1	0	0	0	0	1	1	0	Add memory to A	7
ADC M	1	0	0	0	1	1	1	0	Add memory to A with carry	7
ADI	1	1	0	0	0	1	1	0	Add immediate to A	7
ACI	1	1	0	0	1	1	1	0	Add immediate to A with carry	7
DAD B	0	0	0	0	1	0	0	1	Add B & C to H & L	10
DAD D	0	0	0	1	1	0	0	1	Add D & E to H & L	10
DAD H	0	0	1	0	1	0	0	1	Add H & L to H & L	10
DAD SP	0	0	1	1	1	0	0	1	Add stack pointer to H & L	10

Summary of Processor Instructions (Cont.)

Mnemonic	Instruction Code [1] D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Operations Description	Clock Cycles [2]
SUBTRACT										
SUB r	1	0	0	1	0	S	S	S	Subtract register from A	4
SBB r	1	0	0	1	1	S	S	S	Subtract register from A with borrow	4
SUB M	1	0	0	1	0	1	1	0	Subtract memory from A	7
SBB M	1	0	0	1	1	1	1	0	Subtract memory from A with borrow	7
SUI	1	1	0	1	0	1	1	0	Subtract immediate from A	7
SBI	1	1	0	1	1	1	1	0	Subtract immediate from A with borrow	7
LOGICAL										
ANA r	1	0	1	0	0	S	S	S	And register with A	4
XRA r	1	0	1	0	1	S	S	S	Exclusive Or register with A	4
ORA r	1	0	1	1	0	S	S	S	Or register with A	4
CMP r	1	0	1	1	1	S	S	S	Compare register with A	4
ANA M	1	0	1	0	0	1	1	0	And memory with A	7
XRA M	1	0	1	0	1	1	1	0	Exclusive Or memory with A	7
ORA M	1	0	1	1	0	1	1	0	Or memory with A	7
CMP M	1	0	1	1	1	1	1	0	Compare memory with A	7
ANI	1	1	1	0	0	1	1	0	And immediate with A	7
XRI	1	1	1	0	1	1	1	0	Exclusive Or immediate with A	7
ORI	1	1	1	1	0	1	1	0	Or immediate with A	7
CPI	1	1	1	1	1	1	1	0	Compare immediate with A	7

Mnemonic	Instruction Code [1] D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Operations Description	Clock Cycles [2]
ROTATE										
RLC	0	0	0	0	0	1	1	1	Rotate A left	4
RRC	0	0	0	0	1	1	1	1	Rotate A right	4
RAL	0	0	0	1	0	1	1	1	Rotate A left through carry	4
RAR	0	0	0	1	1	1	1	1	Rotate A right through carry	4
SPECIALS										
CMA	0	0	1	0	1	1	1	1	Complement A	4
STC	0	0	1	1	0	1	1	1	Set carry	4
CMC	0	0	1	1	1	1	1	1	Complement carry	4
DAA	0	0	1	0	0	1	1	1	Decimal adjust A	4
INPUT/OUTPUT										
IN	1	1	0	1	1	0	1	1	Input	10
OUT	1	1	0	1	0	0	1	1	Output	10
CONTROL										
EI	1	1	1	1	1	0	1	1	Enable Interrupts	4
DI	1	1	1	1	0	0	1	1	Disable Interrupt	4
NOP	0	0	0	0	0	0	0	0	No-operation	4
HLT	0	1	1	1	0	1	1	0	Halt	7

NOTES:

1. DDD or SSS: B=000, C=001, D=010, E=011, H=100, L=101, Memory=110, A=111.
2. Two possible cycle times (6/12) indicate instruction cycles dependent on condition flags.

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8085AH/8085AH-2/8085AH-1
8-BIT HMOS MICROPROCESSORS

- **Single +5V Power Supply with 10% Voltage Margins**
- **3 MHz, 5 MHz and 6 MHz Selections Available**
- **20% Lower Power Consumption than 8085A for 3 MHz and 5 MHz**
- **1.3 μs Instruction Cycle (8085AH); 0.8 μs (8085AH-2); 0.67 μs (8085AH-1)**
- **100% Compatible with 8085A**
- **100% Software Compatible with 8080A**
- **On-Chip Clock Generator (with External Crystal, LC or RC Network)**
- **On-Chip System Controller; Advanced Cycle Status Information Available for Large System Control**
- **Four Vectored Interrupt Inputs (One is Non-Maskable) Plus an 8080A-Compatible Interrupt**
- **Serial In/Serial Out Port**
- **Decimal, Binary and Double Precision Arithmetic**
- **Direct Addressing Capability to 64K Bytes of Memory**
- **Available in EXPRESS**
  - **Standard Temperature Range**
  - **Extended Temperature Range**

The Intel® 8085AH is a complete 8 bit parallel Central Processing Unit (CPU) implemented in N-channel, depletion load, silicon gate technology (HMOS). Its instruction set is 100% software compatible with the 8080A microprocessor, and it is designed to improve the present 8080A's performance by higher system speed. Its high level of system integration allows a minimum system of three IC's [8085AH (CPU), 8156H (RAM/IO) and 8355/8755A (ROM/PROM/IO)] while maintaining total system expandability. The 8085AH-2 and 8085AH-1 are faster versions of the 8085AH.

The 8085AH incorporates all of the features that the 8224 (clock generator) and 8228 (system controller) provided for the 8080A, thereby offering a high level of system integration.

The 8085AH uses a multiplexed data bus. The address is split between the 8 bit address bus and the 8 bit data bus. The on-chip address latches of 8155H/8156H/8355/8755A memory products allow a direct interface with the 8085AH.

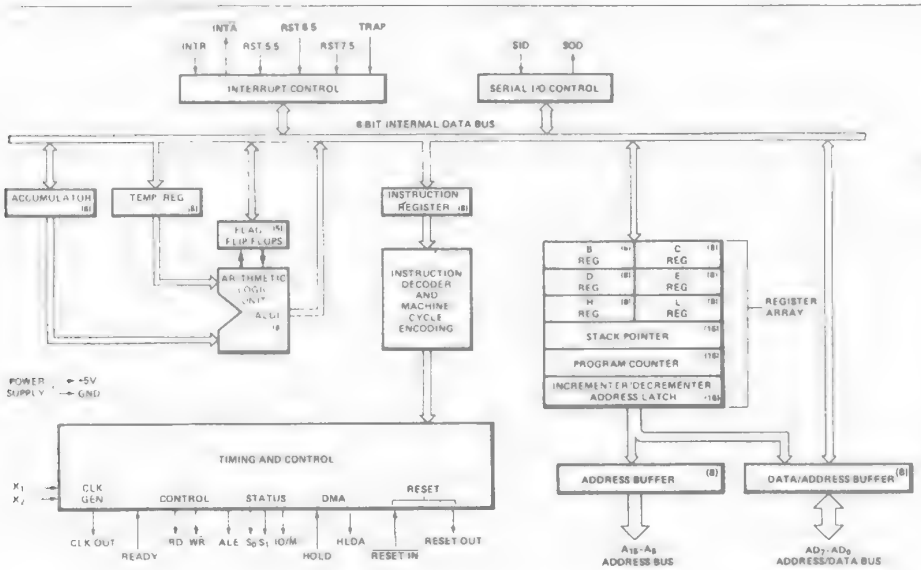

Figure 1. 8085AH CPU Functional Block Diagram

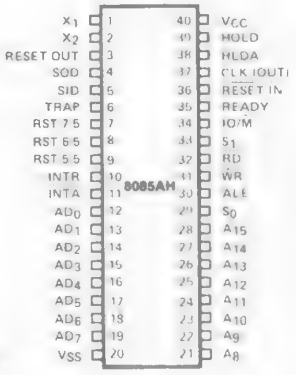

Figure 2. 8085AH Pin Configuration

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Table 1. Pin Description

Symbol	Type	Name and Function
A_8–A_{15}	O	**Address Bus:** The most significant 8 bits of the memory address or the 8 bits of the I/O address, 3-stated during Hold and Halt modes and during RESET.
AD_{0-7}	I/O	**Multiplexed Address/Data Bus:** Lower 8 bits of the memory address (or I/O address) appear on the bus during the first clock cycle (T state) of a machine cycle. It then becomes the data bus during the second and third clock cycles.
ALE	O	**Address Latch Enable:** It occurs during the first clock state of a machine cycle and enables the address to get latched into the on-chip latch of peripherals. The falling edge of ALE is set to guarantee setup and hold times for the address information. The falling edge of ALE can also be used to strobe the status information. ALE is never 3-stated.
S_0, S_1, and IO/$\overline{M}$	O	**Machine Cycle Status:** IO/$\overline{M}$ S_1 S_0 Status 0 0 1 Memory write 0 1 0 Memory read 1 0 1 I/O write 1 1 0 I/O read 0 1 1 Opcode fetch 1 1 1 Opcode fetch 1 1 1 Interrupt Acknowledge * 0 0 Halt * X X Hold * X X Reset * = 3-state (high impedance) X = unspecified S_1 can be used as an advanced R/$\overline{W}$ status. IO/$\overline{M}$, S_0 and S_1 become valid at the beginning of a machine cycle and remain stable throughout the cycle. The falling edge of ALE may be used to latch the state of these lines.
$\overline{RD}$	O	**Read Control:** A low level on $\overline{RD}$ indicates the selected memory or I/O device is to be read and that the Data Bus is available for the data transfer, 3-stated during Hold and Halt modes and during RESET.
$\overline{WR}$	O	**Write Control:** A low level on $\overline{WR}$ indicates the data on the Data Bus is to be written into the selected memory or I/O location. Data is set up at the trailing edge of $\overline{WR}$. 3-stated during Hold and Halt modes and during RESET.

Symbol	Type	Name and Function
READY	I	**Ready:** If READY is high during a read or write cycle, it indicates that the memory or peripheral is ready to send or receive data. If READY is low, the cpu will wait an integral number of clock cycles for READY to go high before completing the read or write cycle. READY must conform to specified setup and hold times.
HOLD	I	**Hold:** Indicates that another master is requesting the use of the address and data buses. The cpu, upon receiving the hold request, will relinquish the use of the bus as soon as the completion of the current bus transfer. Internal processing can continue. The processor can regain the bus only after the HOLD is removed. When the HOLD is acknowledged, the Address, Data $\overline{RD}$, $\overline{WR}$, and IO/$\overline{M}$ lines are 3-stated.
HLDA	O	**Hold Acknowledge:** Indicates that the cpu has received the HOLD request and that it will relinquish the bus in the next clock cycle. HLDA goes low after the Hold request is removed. The cpu takes the bus one half clock cycle after HLDA goes low.
INTR	I	**Interrupt Request:** Is used as a general purpose interrupt. It is sampled only during the next to the last clock cycle of an instruction and during Hold and Halt states. If it is active, the Program Counter (PC) will be inhibited from incrementing and an $\overline{INTA}$ will be issued. During this cycle a RESTART or CALL instruction can be inserted to jump to the interrupt service routine. The INTR is enabled and disabled by software. It is disabled by Reset and immediately after an interrupt is accepted.
$\overline{INTA}$	O	**Interrupt Acknowledge:** Is used instead of (and has the same timing as) $\overline{RD}$ during the Instruction cycle after an INTR is accepted. It can be used to activate an 8259A Interrupt chip or some other interrupt port.
RST 5.5 RST 6.5 RST 7.5	I	**Restart Interrupts:** These three inputs have the same timing as INTR except they cause an internal RESTART to be automatically inserted The priority of these interrupts is ordered as shown in Table 2. These interrupts have a higher priority than INTR. In addition, they may be individually masked out using the SIM instruction.

Table 1. Pin Description (Continued)

Symbol	Type	Name and Function
TRAP	I	**Trap:** Trap interrupt is a non-maskable RESTART interrupt. It is recognized at the same time as INTR or RST 5.5-7.5. It is unaffected by any mask or Interrupt Enable. It has the highest priority of any interrupt. (See Table 2.)
$\overline{\text{RESET IN}}$	I	**Reset In:** Sets the Program Counter to zero and resets the Interrupt Enable and HLDA flip-flops. The data and address buses and the control lines are 3-stated during RESET and because of the asynchronous nature of RESET, the processor's internal registers and flags may be altered by RESET with unpredictable results. $\overline{\text{RESET IN}}$ is a Schmitt-triggered input, allowing connection to an R-C network for power-on RESET delay (see Figure 3). Upon power-up, $\overline{\text{RESET IN}}$ must remain low for at least 10 ms after minimum V_{CC} has been reached. For proper reset operation after the power-up duration, $\overline{\text{RESET IN}}$ should be kept low a minimum of three clock periods. The CPU is held in the reset condition as long as $\overline{\text{RESET IN}}$ is applied.

Symbol	Type	Name and Function
RESET OUT	O	**Reset Out:** Reset Out indicates cpu is being reset. Can be used as a system reset. The signal is synchronized to the processor clock and lasts an integral number of clock periods.
X_1, X_2	I	**X_1 and X_2:** Are connected to a crystal, LC, or RC network to drive the internal clock generator. X_1 can also be an external clock input from a logic gate. The input frequency is divided by 2 to give the processor's internal operating frequency.
CLK	O	**Clock:** Clock output for use as a system clock. The period of CLK is twice the X_1, X_2 input period.
SID	I	**Serial Input Data Line:** The data on this line is loaded into accumulator bit 7 whenever a RIM instruction is executed.
SOD	O	**Serial Output Data Line:** The output SOD is set or reset as specified by the SIM instruction.
V_{CC}		**Power:** +5 volt supply.
V_{SS}		**Ground:** Reference.

Table 2. Interrupt Priority, Restart Address, and Sensitivity

Name	Priority	Address Branched To (1) When Interrupt Occurs	Type Trigger
TRAP	1	24H	Rising edge AND high level until sampled.
RST 7.5	2	3CH	Rising edge (latched).
RST 6.5	3	34H	High level until sampled.
RST 5.5	4	2CH	High level until sampled.
INTR	5	See Note (2).	High level until sampled.

NOTES:
1. The processor pushes the PC on the stack before branching to the indicated address.
2. The address branched to depends on the instruction provided to the cpu when the interrupt is acknowledged.

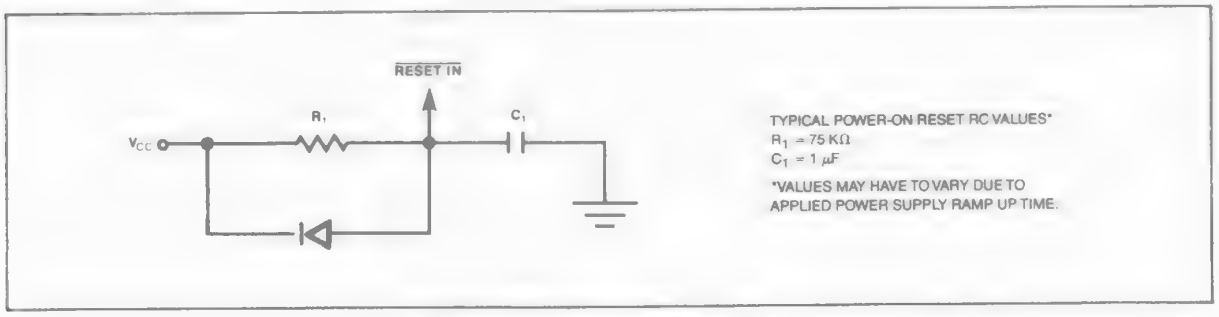


Figure 3. Power-On Reset Circuit

FUNCTIONAL DESCRIPTION

The 8085AH is a complete 8-bit parallel central processor. It is designed with N-channel, depletion load, silicon gate technology (HMOS), and requires a single +5 volt supply. Its basic clock speed is 3 MHz (8085AH), 5 MHz (8085AH-2), or 6 MHz (8085AH-1), thus improving on the present 8080A's performance with higher system speed. Also it is designed to fit into a minimum system of three IC's: The CPU (8085AH), a RAM/IO (8156H), and a ROM or EPROM/IO chip (8355 or 8755A).

The 8085AH has twelve addressable 8-bit registers. Four of them can function only as two 16-bit register pairs. Six others can be used interchangeably as 8-bit registers or as 16-bit register pairs. The 8085AH register set is as follows:

Mnemonic	Register	Contents
ACC or A	Accumulator	8 bits
PC	Program Counter	16-bit address
BC,DE,HL	General-Purpose Registers; data pointer (HL)	8 bits x 6 or 16 bits x 3
SP	Stack Pointer	16-bit address
Flags or F	Flag Register	5 flags (8-bit space)

The 8085AH uses a multiplexed Data Bus. The address is split between the higher 8-bit Address Bus and the lower 8-bit Address/Data Bus. During the first T state (clock cycle) of a machine cycle the low order address is sent out on the Address/Data bus. These lower 8 bits may be latched externally by the Address Latch Enable signal (ALE). During the rest of the machine cycle the data bus is used for memory or I/O data.

The 8085AH provides $\overline{RD}$, $\overline{WR}$, S_0, S_1, and IO/$\overline{M}$ signals for bus control. An Interrupt Acknowledge signal ($\overline{INTA}$) is also provided. HOLD and all Interrupts are synchronized with the processor's internal clock. The 8085AH also provides Serial Input Data (SID) and Serial Output Data (SOD) lines for simple serial interface.

In addition to these features, the 8085AH has three maskable, vector interrupt pins, one nonmaskable TRAP interrupt, and a bus vectored interrupt, INTR.

INTERRUPT AND SERIAL I/O

The 8085AH has 5 interrupt inputs: INTR, RST 5.5, RST 6.5, RST 7.5, and TRAP. INTR is identical in function to the 8080A INT. Each of the three RESTART inputs, 5.5, 6.5, and 7.5, has a programmable mask. TRAP is also a RESTART interrupt but it is nonmaskable.

The three maskable interrupts cause the internal execution of RESTART (saving the program counter in the stack and branching to the RESTART address) if the interrupts are enabled and if the interrupt mask is not set. The nonmaskable TRAP causes the internal execution of a RESTART vector independent of the state of the interrupt enable or masks. (See Table 2.)

There are two different types of inputs in the restart interrupts. RST 5.5 and RST 6.5 are *high level-sensitive* like INTR (and INT on the 8080) and are recognized with the same timing as INTR. RST 7.5 is *rising edge-sensitive.*

For RST 7.5, only a pulse is required to set an internal flip-flop which generates the internal interrupt request (a normally high level signal with a low going pulse is recommended for highest system noise immunity). The RST 7.5 request flip-flop remains set until the request is serviced. Then it is reset automatically. This flip-flop may also be reset by using the SIM instruction or by issuing a $\overline{RESET\ IN}$ to the 8085AH. The RST 7.5 internal flip-flop will be set by a pulse on the RST 7.5 pin even when the RST 7.5 interrupt is masked out.

The status of the three RST interrupt masks can only be affected by the SIM instruction and $\overline{RESET\ IN}$. (See SIM, Chapter 5 of the MCS-80/85 User's Manual.)

The interrupts are arranged in a fixed priority that determines which interrupt is to be recognized if more than one is pending as follows: TRAP—highest priority, RST 7.5, RST 6.5, RST 5.5, INTR—lowest priority. This priority scheme does not take into account the priority of a routine that was started by a higher priority interrupt. RST 5.5 can interrupt an RST 7.5 routine if the interrupts are re-enabled before the end of the RST 7.5 routine.

The TRAP interrupt is useful for catastrophic events such as power failure or bus error. The TRAP input is recognized just as any other interrupt but has the highest priority. It is not affected by any flag or mask. The TRAP input is both *edge and level sensitive*. The TRAP input must go high and remain high until it is acknowledged. It will not be recognized again until it goes low, then high again. This avoids any false triggering due to noise or logic glitches. Figure 4 illustrates the TRAP interrupt request circuitry within the 8085AH. Note that the servicing of any interrupt (TRAP, RST 7.5, RST 6.5, RST 5.5, INTR) disables all future interrupts (except TRAPs) until an EI instruction is executed.

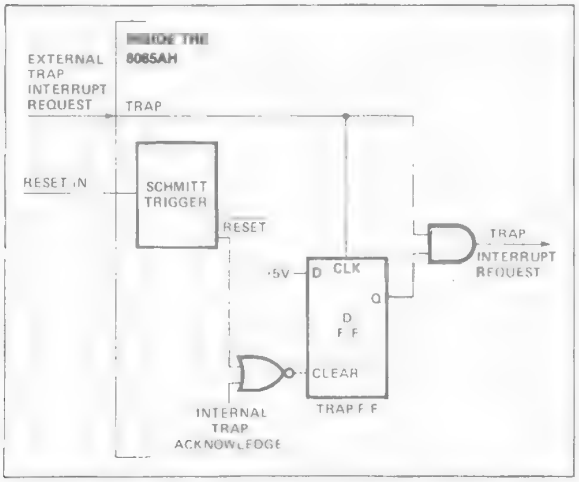


Figure 4. TRAP and RESET IN Circuit

The TRAP interrupt is special in that it disables interrupts, but preserves the previous interrupt enable status. Performing the first RIM instruction following a TRAP interrupt allows you to determine whether interrupts were enabled or disabled prior to the TRAP. All subsequent RIM instructions provide current interrupt enable status. Performing a RIM instruction following INTR, or RST 5.5–7.5 will provide current Interrupt Enable status, revealing that Interrupts are disabled. See the description of the RIM instruction in the MCS-80/85 Family User's Manual.

The serial I/O system is also controlled by the RIM and SIM instructions. SID is read by RIM, and SIM sets the SOD data.

DRIVING THE X_1 AND X_2 INPUTS

You may drive the clock inputs of the 8085AH, 8085AH-2, or 8085AH-1 with a crystal, an LC tuned circuit, an RC network, or an external clock source. The crystal frequency must be at least 1 MHz, and must be twice the desired internal clock frequency; hence, the 8085AH is operated with a 6 MHz crystal (for 3 MHz clock), the 8085AH-2 operated with a 10 MHz crystal (for 5 MHz clock), and the 8085AH-1 can be operated with a 12 MHz crystal (for 6 MHz clock). If a crystal is used, it must have the following characteristics:

Parallel resonance at twice the clock frequency desired
C_L (load capacitance) $\leq$ 30 pF
C_S (shunt capacitance) $\leq$ 7 pF
R_S (equivalent shunt resistance) $\leq$ 75 Ohms
Drive level: 10 mW
Frequency tolerance: $\pm$.005% (suggested)

Note the use of the 20 pF capacitor between X_2 and ground. This capacitor is required with crystal frequencies below 4 MHz to assure oscillator startup at the correct frequency. A parallel-resonant LC circuit may be used as the frequency-determining network for the 8085AH, providing that its frequency tolerance of approximately $\pm$10% is acceptable. The components are chosen from the formula:

$$f = \frac{1}{2\pi\sqrt{L(C_{ext} + C_{int})}}$$

To minimize variations in frequency, it is recommended that you choose a value for C_{ext} that is at least twice that of C_{int}, or 30 pF. The use of an LC circuit is not recommended for frequencies higher than approximately 5 MHz.

An RC circuit may be used as the frequency-determining network for the 8085AH if maintaining a precise clock frequency is of no importance. Variations in the on-chip timing generation can cause a wide variation in frequency when using the RC mode. Its advantage is its low component cost. The driving frequency generated by the circuit shown is approximately 3 MHz. It is not recommended that frequencies greatly higher or lower than this be attempted.

Figure 5 shows the recommended clock driver circuits. Note in D and E that pullup resistors are required to assure that the high level voltage of the input is at least 4V and maximum low level voltage of 0.8V.

For driving frequencies up to and including 6 MHz you may supply the driving signal to X_1 and leave X_2 open-circuited (Figure 5D). If the driving frequency is from 6 MHz to 12 MHz, stability of the clock generator will be improved by driving both X_1 and X_2 with a push-pull source (Figure 5E). To prevent self-oscillation of the 8085AH, be sure that X_2 is not coupled back to X_1 through the driving circuit.

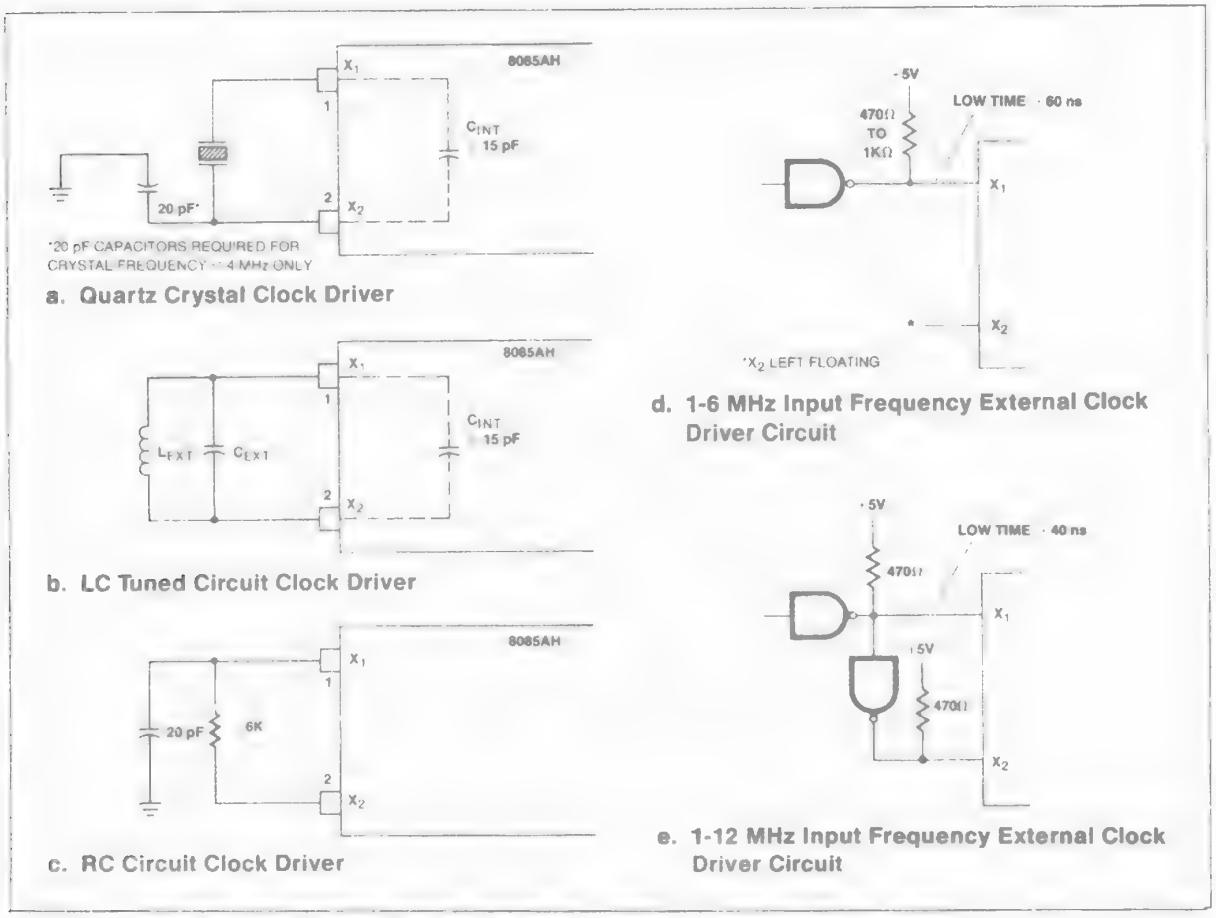


Figure 5. Clock Driver Circuits

GENERATING AN 8085AH WAIT STATE

If your system requirements are such that slow memories or peripheral devices are being used, the circuit shown in Figure 6 may be used to insert one WAIT state in each 8085AH machine cycle.

The D flip-flops should be chosen so that

- CLK is rising edge-triggered
- CLEAR is low-level active.

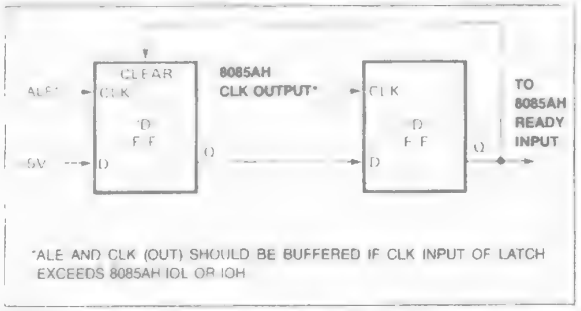


Figure 6. Generation of a Wait State for 8085AH CPU

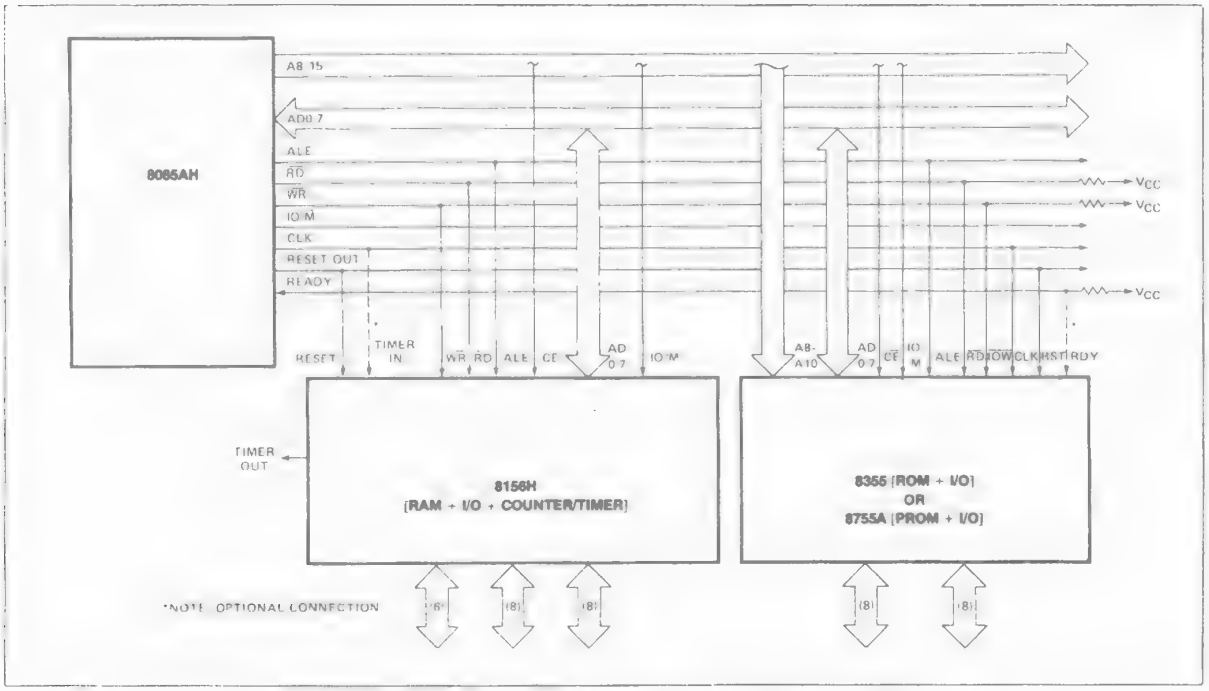


Figure 8. MCS-85® Minimum System (Memory Mapped I/O)

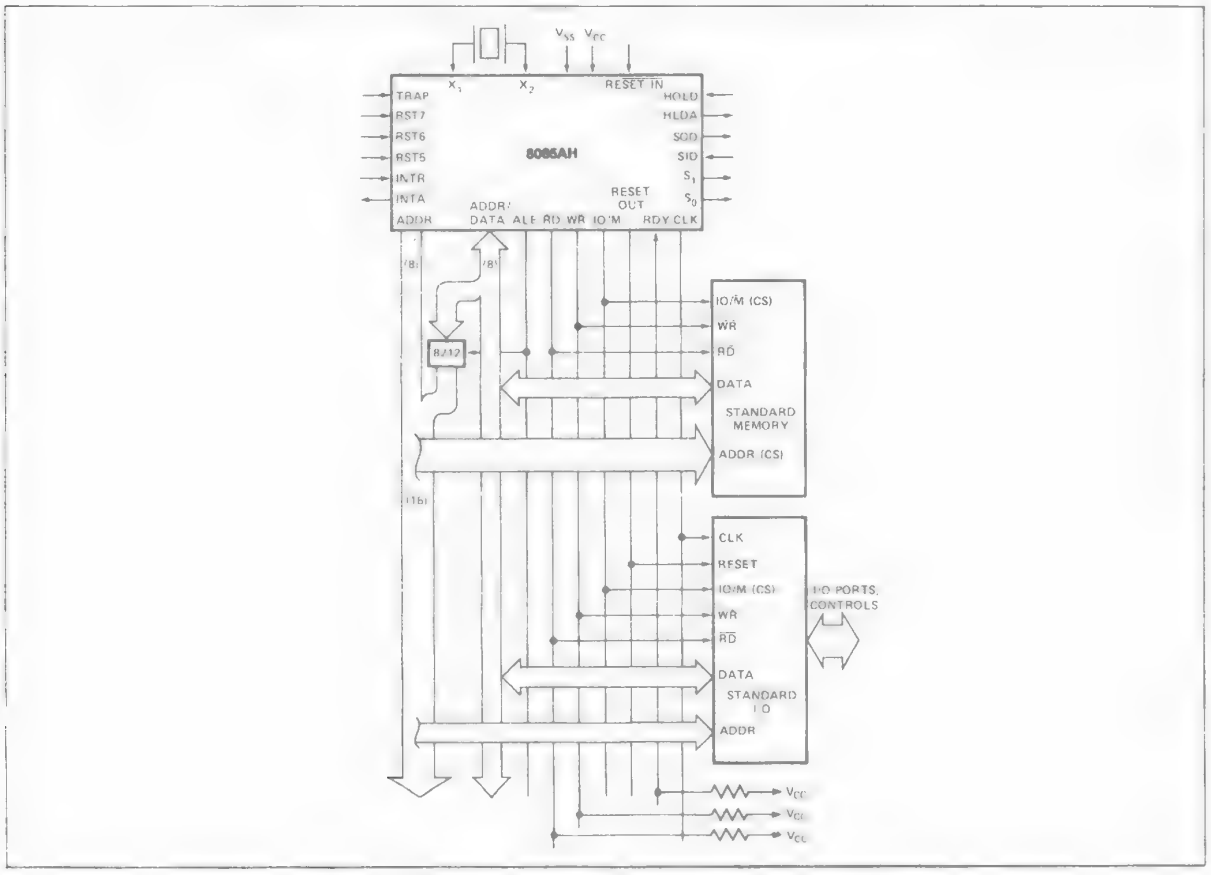


Figure 9. MCS-85® System (Using Standard Memories)

As in the 8080, the READY line is used to extend the read and write pulse lengths so that the 8085AH can be used with slow memory. HOLD causes the CPU to relinquish the bus when it is through with it by floating the Address and Data Buses.

SYSTEM INTERFACE

The 8085AH family includes memory components, which are directly compatible to the 8085AH CPU. For example, a system consisting of the three chips, 8085AH, 8156H, and 8355 will have the following features:

- 2K Bytes ROM
- 256 Bytes RAM
- 1 Timer/Counter
- 4 8-bit I/O Ports
- 1 6-bit I/O Port
- 4 Interrupt Levels
- Serial In/Serial Out Ports

This minimum system, using the standard I/O technique is as shown in Figure 7.

In addition to standard I/O, the memory mapped I/O offers an efficient I/O addressing technique. With this technique, an area of memory address space is assigned for I/O address, thereby, using the memory address for I/O manipulation. Figure 8 shows the system configuration of Memory Mapped I/O using 8085AH.

The 8085AH CPU can also interface with the standard memory that does *not* have the multiplexed address/data bus. It will require a simple 8212 (8-bit latch) as shown in Figure 9.

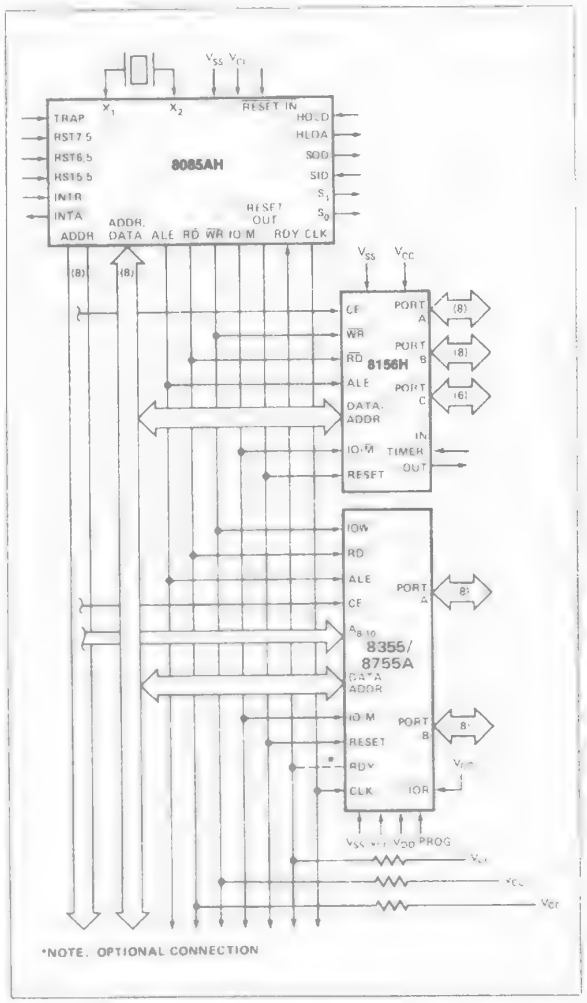


Figure 7. 8085AH Minimum System (Standard I/O Technique)

BASIC SYSTEM TIMING

The 8085AH has a multiplexed Data Bus. ALE is used as a strobe to sample the lower 8-bits of address on the Data Bus. Figure 10 shows an instruction fetch, memory read and I/O write cycle (as would occur during processing of the OUT instruction). Note that during the I/O write and read cycle that the I/O port address is copied on both the upper and lower half of the address.

There are seven possible types of machine cycles. Which of these seven takes place is defined by the status of the three status lines ($IO/\overline{M}$, S_1, S_0) and the three control signals ($\overline{RD}$, $\overline{WR}$, and $\overline{INTA}$). (See Table 3.) The status lines can be used as advanced controls (for device selection, for example), since they become active at the T_1 state, at the outset of each machine cycle. Control lines $\overline{RD}$ and $\overline{WR}$ become active later, at the time when the transfer of data is to take place, so are used as command lines.

A machine cycle normally consists of three T states, with the exception of OPCODE FETCH, which normally has either four or six T states (unless WAIT or HOLD states are forced by the receipt of $\overline{READY}$ or HOLD inputs). Any T state must be one of ten possible states, shown in Table 4.

Table 3. 8085AH Machine Cycle Chart

MACHINE CYCLE			STATUS IO/M	S1	S0	CONTROL RD	WR	INTA
OPCODE FETCH	(OF)		0	1	1	0	1	1
MEMORY READ	(MR)		0	1	0	0	1	1
MEMORY WRITE	(MW)		0	0	1	1	0	1
I/O READ	(IOR)		1	1	0	0	1	1
I/O WRITE	(IOW)		1	0	1	1	0	1
ACKNOWLEDGE OF INTR	(INA)		1	1	1	1	1	0
BUS IDLE	(BI)	(DAD)	0	1	0	1	1	1
		ACK. OF RST,TRAP	1	1	1	1	1	1
		HALT	TS	0	0	TS	TS	1

Table 4. 8085AH Machine State Chart

Machine State	Status & Buses S1,S0	IO/M	A_8-A_{15}	AD_0-AD_7	Control RD	WR	INTA	ALE
T_1	X	X	X	X	1	1	1	1*
T_2	X	X	X	X	X	X	0	
T_{WAIT}	X	X	X	X	X	X	0	
T_3	X	X	X	X	X	X	0	
T_4	1	0†	X	TS	1	1	0	
T_5	1	0†	X	TS	1	1	0	
T_6	1	0†	X	TS	1	1	0	
T_{RESET}	X	TS	TS	TS	TS	1	0	
T_{HALT}	0	TS	TS	TS	TS	1	0	
T_{HOLD}	X	TS	TS	TS	TS	1	0	

0 = Logic "0" TS = High Impedance
1 = Logic "1" X = Unspecified

* ALE not generated during 2nd and 3rd machine cycles of DAD instruction.
† IO/M = 1 during T_4-T_6 of INA machine cycle

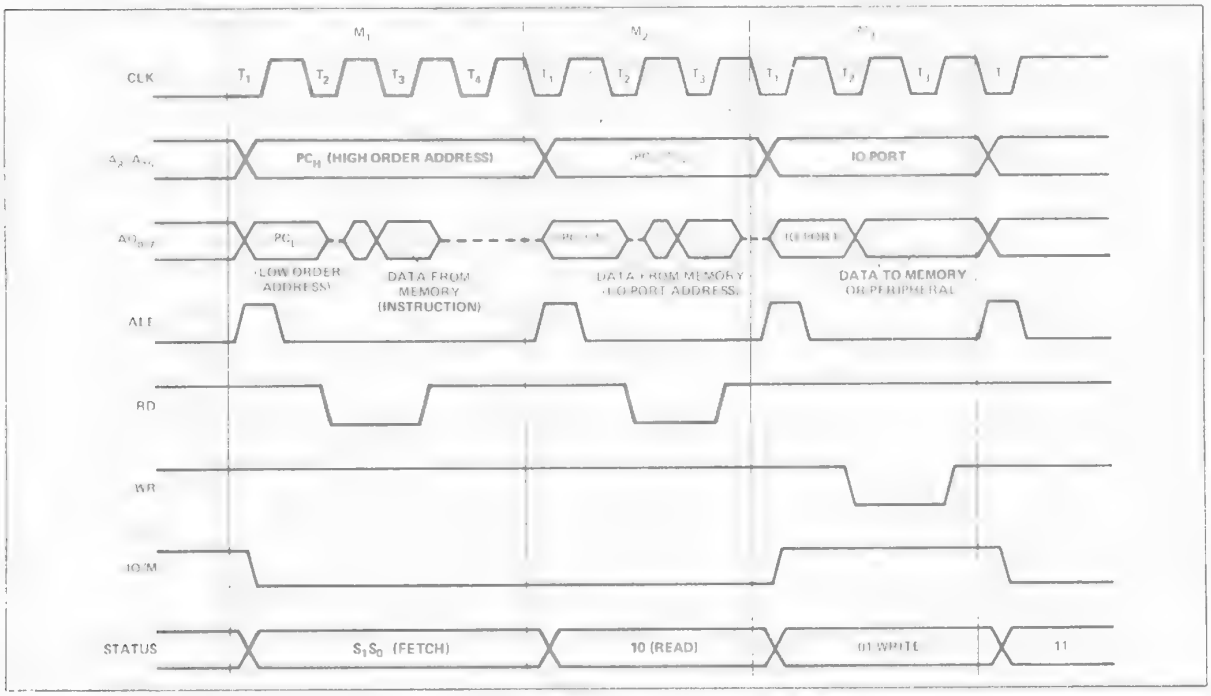


Figure 10. 8085AH Basic System Timing

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage on Any Pin
With Respect to Ground ..... −0.5V to +7V
Power Dissipation ..... 1.5 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS

8085AH, 8085AH-2: (T_A = 0°C to 70°C, V_{CC} = 5V ±10%, V_{SS} =0V; unless otherwise specified)*
8085AH-1: (T_A = 0°C to 70°C, V_{CC} = 5V ±5%, V_{SS} = 0V; unless otherwise specified)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	+0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400μA
I_{CC}	Power Supply Current		135	mA	8085AH, 8085AH-2
			200	mA	8085AH-1 (Preliminary)
I_{IL}	Input Leakage		±10	μA	$0 \leq V_{IN} \leq V_{CC}$
I_{LO}	Output Leakage		±10	μA	$0.45V \leq V_{OUT} \leq V_{CC}$
V_{ILR}	Input Low Level, RESET	−0.5	+0.8	V	
V_{IHR}	Input High Level, RESET	2.4	V_{CC} +0.5	V	
V_{HY}	Hysteresis, RESET	0.25		V	

A.C. CHARACTERISTICS

8085AH, 8085AH-2: (T_A = 0°C to 70°C, V_{CC} = 5V ±10%, V_{SS} = OV)*
8085AH-1: (T_A = 0°C to 70°C, V_{CC} = 5V ±5%, V_{SS} = 0V)

Symbol	Parameter	8085AH[2] (Final)		8085AH-2[2] (Final)		8085AH-1 (Preliminary)		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{CYC}	CLK Cycle Period	320	2000	200	2000	167	2000	ns
t_1	CLK Low Time (Standard CLK Loading)	80		40		20		ns
t_2	CLK High Time (Standard CLK Loading)	120		70		50		ns
t_r, t_f	CLK Rise and Fall Time		30		30		30	ns
t_{XKR}	X_1 Rising to CLK Rising	25	120	25	100	20	100	ns
t_{XKF}	X_1 Rising to CLK Falling	30	150	30	110	25	110	ns
t_{AC}	A_{8-15} Valid to Leading Edge of Control[1]	270		115		70		ns
t_{ACL}	A_{0-7} Valid to Leading Edge of Control	240		115		60		ns
t_{AD}	A_{0-15} Valid to Valid Data In		575		350		225	ns
t_{AFR}	Address Float After Leading Edge of $\overline{READ}$ ($\overline{INTA}$)		0		0		0	ns
t_{AL}	A_{8-15} Valid Before Trailing Edge of ALE[1]	115		50		25		ns

*Note: For Extended Temperature EXPRESS use M8085AH Electricals Parameters.

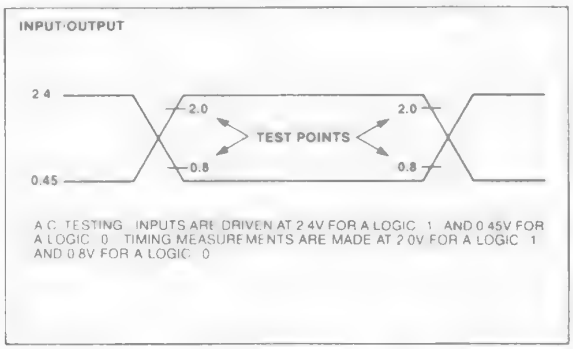
A.C. CHARACTERISTICS (Continued)

Symbol	Parameter	8085AH[2] (Final)		8085AH-2[2] (Final)		8085AH-1 (Preliminary)		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{ALL}	A_{0-7} Valid Before Trailing Edge of ALE	80		50		25		ns
t_{ARY}	READY Valid from Address Valid		220		100		40	ns
t_{CA}	Address (A_{8-15}) Valid After Control	120		60		30		ns
t_{CC}	Width of Control Low ($\overline{RD}$, $\overline{WR}$, $\overline{INTA}$) Edge of ALE	400		230		150		ns
t_{CL}	Trailing Edge of Control to Leading Edge of ALE	50		25		0		ns
t_{DW}	Data Valid to Trailing Edge of $\overline{WRITE}$	420		230		140		ns
t_{HABE}	HLDA to Bus Enable		210		150		150	ns
t_{HABF}	Bus Float After HLDA		210		150		150	ns
t_{HACK}	HLDA Valid to Trailing Edge of CLK	110		40		0		ns
t_{HDH}	HOLD Hold Time	0		0		0		ns
t_{HDS}	HOLD Setup Time to Trailing Edge of CLK	170		120		120		ns
t_{INH}	INTR Hold Time	0		0		0		ns
t_{INS}	INTR, RST, and TRAP Setup Time to Falling Edge of CLK	160		150		150		ns
t_{LA}	Address Hold Time After ALE	100		50		20		ns
t_{LC}	Trailing Edge of ALE to Leading Edge of Control	130		60		25		ns
t_{LCK}	ALE Low During CLK High	100		50		15		ns
t_{LDR}	ALE to Valid Data During Read		460		270		175	ns
t_{LDW}	ALE to Valid Data During Write		200		120		110	ns
t_{LL}	ALE Width	140		80		50		ns
t_{LRY}	ALE to READY Stable		110		30		10	ns
t_{RAE}	Trailing Edge of $\overline{READ}$ to Re-Enabling of Address	150		90		50		ns
t_{RD}	$\overline{READ}$ (or $\overline{INTA}$) to Valid Data		300		150		75	ns
t_{RV}	Control Trailing Edge to Leading Edge of Next Control	400		220		160		ns
t_{RDH}	Data Hold Time After $\overline{READ}$ $\overline{INTA}$	0		0		0		ns
t_{RYH}	READY Hold Time	0		0		5		ns
t_{RYS}	READY Setup Time to Leading Edge of CLK	110		100		100		ns
t_{WD}	Data Valid After Trailing Edge of $\overline{WRITE}$	100		60		30		ns
t_{WDL}	LEADING Edge of $\overline{WRITE}$ to Data Valid		40		20		30	ns

NOTES:

1. A_8–A_{15} address Specs apply IO/$\overline{M}$, S_0, and S_1 except A_8–A_{15} are undefined during T_4–T_6 of OF cycle whereas IO/$\overline{M}$, S_0, and S_1 are stable.
2. *Test Conditions:* t_{CYC} = 320 ns (8085AH)/200 ns (8085AH-2);/ 167 ns (8085AH-1); C_L = 150 pF.
3. For all output timing where $C_L \neq 150$ pF use the following correction factors:
   25 pF $\leq C_L <$ 150 pF: −0.10 ns/pF
   150 pF $< C_L \leq$ 300 pF: +0.30 ns/pF
4. Output timings are measured with purely capacitive load.
5. To calculate timing specifications at other values of t_{CYC} use Table 5.

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING LOAD CIRCUIT

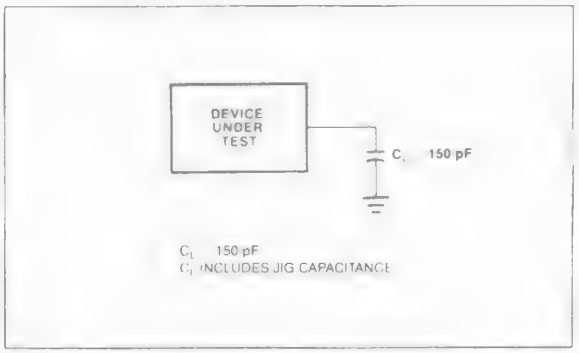


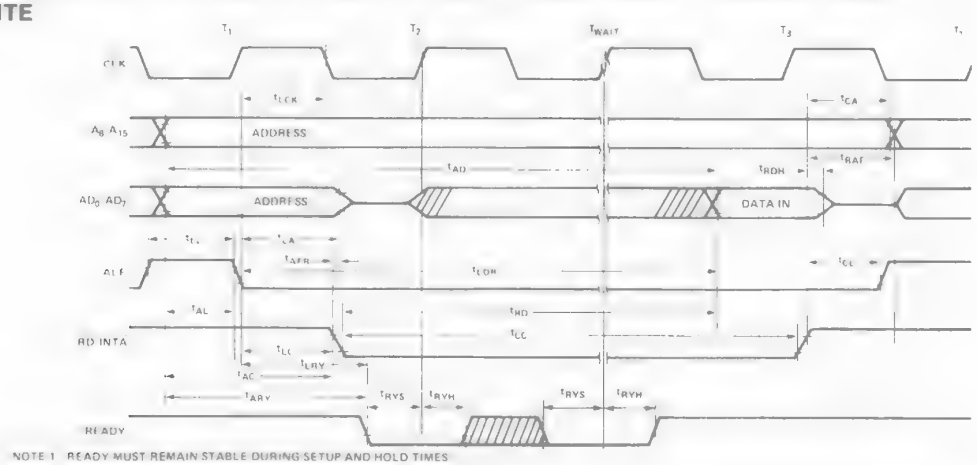
Table 5. Bus Timing Specification as a T_{CYC} Dependent

Symbol	8085AH	8085AH-2	8085AH-1	
t_{AL}	(1/2) T − 45	(1/2) T − 50	(1/2) T − 58	Minimum
t_{LA}	(1/2) T − 60	(1/2) T − 50	(1/2) T − 63	Minimum
t_{LL}	(1/2) T − 20	(1/2) T − 20	(1/2) T − 33	Minimum
t_{LCK}	(1/2) T − 60	(1/2) T − 50	(1/2) T − 68	Minimum
t_{LC}	(1/2) T − 30	(1/2) T − 40	(1/2) T − 58	Minimum
t_{AD}	(5/2 + N) T − 225	(5/2 + N) T − 150	(5/2 + N) T − 192	Maximum
t_{RD}	(3/2 + N) T − 180	(3/2 + N) T − 150	(3/2 + N) T − 175	Maximum
t_{RAE}	(1/2) T − 10	(1/2) T − 10	(1/2) T − 33	Minimum
t_{CA}	(1/2) T − 40	(1/2) T − 40	(1/2) T − 53	Minimum
t_{DW}	(3/2 + N) T − 60	(3/2 + N) T − 70	(3/2 + N) T − 110	Minimum
t_{WD}	(1/2) T − 60	(1/2) T − 40	(1/2) T − 53	Minimum
t_{CC}	(3/2 + N) T − 80	(3/2 + N) T − 70	(3/2 + N) T − 100	Minimum
t_{CL}	(1/2) T − 110	(1/2) T − 75	(1/2) T − 83	Minimum
t_{ARY}	(3/2) T − 260	(3/2) T − 200	(3/2) T − 210	Maximum
t_{HACK}	(1/2) T − 50	(1/2) T − 60	(1/2) T − 83	Minimum
t_{HABF}	(1/2) T + 50	(1/2) T + 50	(1/2) T + 67	Maximum
t_{HABE}	(1/2) T + 50	(1/2) T + 50	(1/2) T + 67	Maximum
t_{AC}	(2/2) T − 50	(2/2) T − 85	(2/2) T − 97	Minimum
t_1	(1/2) T − 80	(1/2) T − 60	(1/2) T − 63	Minimum
t_2	(1/2) T − 40	(1/2) T − 30	(1/2) T − 33	Minimum
t_{RV}	(3/2) T − 80	(3/2) T − 80	(3/2) T − 90	Minimum
t_{LDR}	(4/2) T − 180	(4/2) T − 130	(4/2) T − 159	Maximum

NOTE: N is equal to the total WAIT states. T = t_{CYC}.

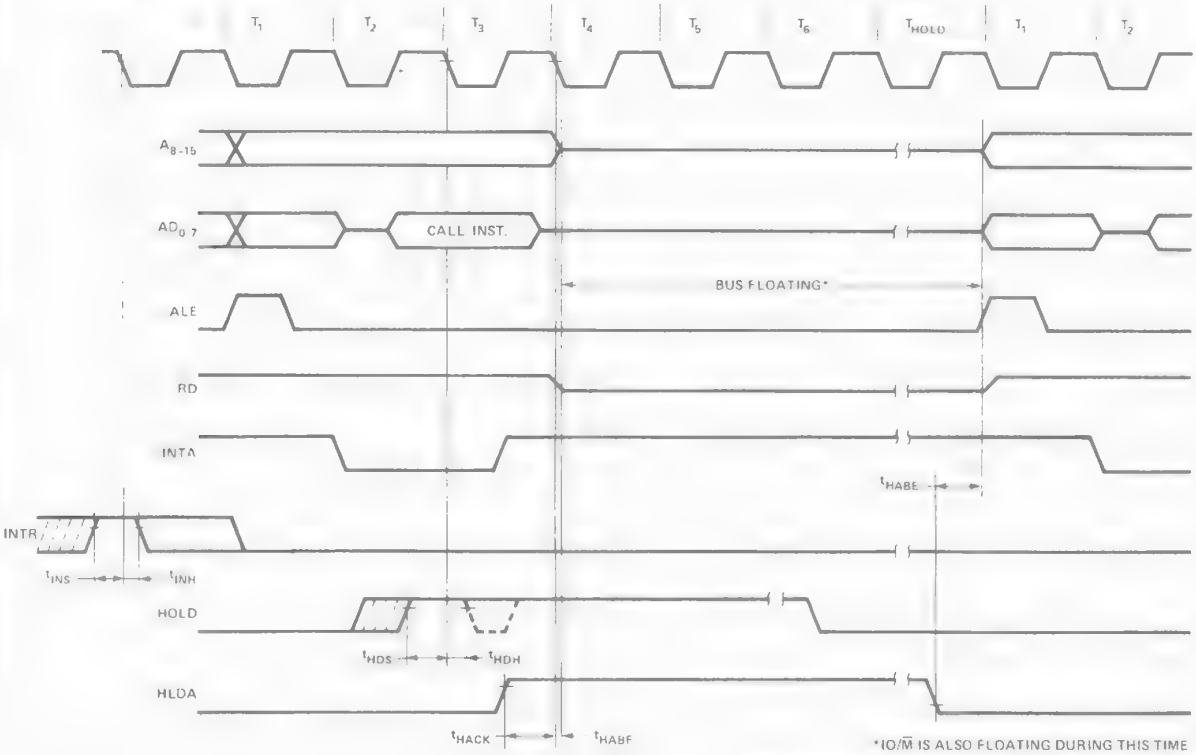
WAVEFORMS (Continued)

READ OPERATION WITH WAIT CYCLE (TYPICAL) — SAME READY TIMING APPLIES TO WRITE



NOTE 1 READY MUST REMAIN STABLE DURING SETUP AND HOLD TIMES

INTERRUPT AND HOLD



*IO/M IS ALSO FLOATING DURING THIS TIME

AFN-01835C

Table 6. Instruction Set Summary

Mnemonic	Instruction Code D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Operations Description
MOVE, LOAD, AND STORE									
MOVr1 r2	0	1	D	D	D	S	S	S	Move register to register
MOV M,r	0	1	1	1	0	S	S	S	Move register to memory
MOV r,M	0	1	[illegible]	D	D	1	1	0	Move memory to register
MVI r	0	0	D	D	D	1	1	0	Move immediate register
MVI M	0	0	1	1	0	1	1	0	Move immediate memory
LXI B	0	0	0	0	0	0	0	1	Load immediate register Pair B & C
LXI D	0	0	0	1	0	0	0	1	Load immediate register Pair D & E
LXI H	0	0	1	0	0	0	0	1	Load immediate register Pair H & L
STAX B	0	0	0	0	0	0	1	0	Store A indirect
STAX D	0	0	0	1	0	0	1	0	Store A indirect
LDAX B	0	0	0	0	1	0	1	0	Load A indirect
LDAX D	0	0	0	1	1	0	1	0	Load A indirect
STA	0	0	1	1	0	0	1	0	Store A direct
LDA	0	0	1	1	1	0	1	0	Load A direct
SHLD	0	0	1	0	0	0	1	0	Store H & L direct
LHLD	0	0	1	0	1	0	1	0	Load H & L direct
XCHG	1	1	1	0	1	0	1	1	Exchange D & E, H & L Registers
STACK OPS									
PUSH B	1	1	0	0	0	1	0	1	Push register Pair B & C on stack
PUSH D	1	1	0	1	0	1	0	1	Push register Pair D & E on stack
PUSH H	1	1	1	0	0	1	0	1	Push register Pair H & L on stack
PUSH PSW	1	1	1	1	0	1	0	1	Push A and Flags on stack
POP B	1	1	0	0	0	0	0	1	Pop register Pair B & C off stack
POP D	1	1	0	1	0	0	0	1	Pop register Pair D & E off stack
POP H	1	1	1	0	0	0	0	1	Pop register Pair H & L off stack
POP PSW	1	1	1	1	0	0	0	1	Pop A and Flags off stack
XTHL	1	1	1	0	0	0	1	1	Exchange top of stack, H & L
SPHL	1	1	1	1	1	0	0	1	H & L to stack pointer
LXI SP	0	0	1	1	0	0	0	1	Load immediate stack pointer
INX SP	0	0	1	1	0	0	1	1	Increment stack pointer
DCX SP	0	0	1	1	1	0	1	1	Decrement stack pointer
JUMP									
JMP	1	1	0	0	0	0	1	1	Jump unconditional
JC	1	1	0	1	1	0	1	0	Jump on carry
JNC	1	1	0	1	0	0	1	0	Jump on no carry
JZ	1	1	0	0	1	0	1	0	Jump on zero
JNZ	1	1	0	0	0	0	1	0	Jump on no zero
JP	1	1	1	1	0	0	1	0	Jump on positive
JM	1	1	1	1	1	0	1	0	Jump on minus
JPE	1	1	1	0	1	0	1	0	Jump on parity even
JPO	1	1	1	0	0	0	1	0	Jump on parity odd
PCHL	1	1	1	0	1	0	0	1	H & L to program counter
CALL									
CALL	1	1	0	0	1	1	0	1	Call unconditional
CC	1	1	0	1	1	1	0	0	Call on carry
CNC	1	1	0	1	0	1	0	0	Call on no carry
CZ	1	1	0	0	1	1	0	0	Call on zero
CNZ	1	1	0	0	0	1	0	0	Call on no zero
CP	1	1	1	1	0	1	0	0	Call on positive
CM	1	1	1	1	1	1	0	0	Call on minus
CPE	1	1	1	0	1	1	0	0	Call on parity even
CPO	1	1	1	0	0	1	0	0	Call on parity odd
RETURN									
RET	1	1	0	0	1	0	0	1	Return
RC	1	1	0	1	1	0	0	0	Return on carry
RNC	1	1	0	1	0	0	0	0	Return on no carry
RZ	1	1	0	0	1	0	0	0	Return on zero
RNZ	1	1	0	0	0	0	0	0	Return on no zero
RP	1	1	1	1	0	0	0	0	Return on positive
RM	1	1	1	1	1	0	0	0	Return on minus
RPE	1	1	1	0	1	0	0	0	Return on parity even
RPO	1	1	1	0	0	0	0	0	Return on parity odd
RESTART									
RST	1	1	A	A	A	1	1	1	Restart
INPUT/OUTPUT									
IN	1	1	0	1	1	0	1	1	Input
OUT	1	1	0	1	0	0	1	1	Output
INCREMENT AND DECREMENT									
INR r	0	0	D	D	D	1	0	0	Increment register
DCR r	0	0	D	D	D	1	0	1	Decrement register
INR M	0	0	1	1	0	1	0	0	Increment memory
DCR M	0	0	1	1	0	1	0	1	Decrement memory
INX B	0	0	0	0	0	0	1	1	Increment B & C registers
INX D	0	0	0	1	0	0	1	1	Increment D & E registers
INX H	0	0	1	0	0	0	1	1	Increment H & L registers
DCX B	0	0	0	0	1	0	1	1	Decrement B & C
DCX D	0	0	0	1	1	0	1	1	Decrement D & E
DCX H	0	0	1	0	1	0	1	1	Decrement H & L
ADD									
ADD r	1	0	0	0	0	S	S	[illegible]	Add register to A
ADC r	1	0	0	0	1	S	S	S	Add register to A with carry
ADD M	1	0	C	0	0	1	1	0	Add memory to A
ADC M	1	0	0	0	1	1	1	0	Add memory to A with carry
ADI	1	1	0	0	0	1	1	0	Add immediate to A
ACI	1	1	0	0	1	1	1	0	Add immediate to A with carry
DAD B	0	0	0	0	1	0	0	1	Add B & C to H & L
DAD D	0	0	0	1	1	0	0	1	Add D & E to H & L
DAD H	0	0	1	0	1	0	0	1	Add H & L to H & L
DAD SP	0	0	1	1	1	0	0	1	Add stack pointer to H & L
SUBTRACT									
SUB r	1	0	0	1	0	S	S	S	Subtract register from A
SBB r	1	0	0	1	1	S	S	S	Subtract register from A with borrow
SUB M	1	0	0	1	0	1	1	0	Subtract memory from A
[illegible]	1	0	0	1	1	1	1	0	Subtract memory from A with borrow
SUI	1	1	0	1	0	1	1	0	Subtract immediate from A
SBI	1	1	0	1	1	1	1	0	Subtract immediate from A with borrow

Table 6. Instruction Set Summary (Continued)

Mnemonic	Instruction Code D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Operations Description
LOGICAL									
ANA r	1	0	1	0	0	S	S	S	And register with A
XRA r	1	0	1	0	1	S	S	S	Exclusive OR register with A
ORA r	1	0	1	1	0	S	S	S	OR register with A
CMP r	1	0	1	1	1	S	S	S	Compare register with A
ANA M	1	0	1	0	0	1	1	0	And memory with A
XRA M	1	0	1	0	1	1	1	0	Exclusive OR memory with A
ORA M	1	0	1	1	0	1	1	0	OR memory with A
CMP M	1	0	1	1	1	1	1	0	Compare memory with A
ANI	1	1	1	0	0	1	1	0	And immediate with A
XRI	1	1	1	0	1	1	1	0	Exclusive OR immediate with A
ORI	1	1	1	1	0	1	1	0	OR immediate with A
CPI	1	1	1	1	1	1	1	0	Compare immediate with A
ROTATE									
RLC	0	0	0	0	0	1	1	1	Rotate A left
RRC	0	0	0	0	1	1	1	1	Rotate A right
RAL	0	0	0	1	0	1	1	1	Rotate A left through carry
RAR	0	0	0	1	1	1	1	1	Rotate A right through carry

Mnemonic	Instruction Code D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Operations Description
SPECIALS									
CMA	0	0	1	0	1	1	1	1	Complement A
STC	0	0	1	1	0	1	1	1	Set carry
CMC	0	0	1	1	1	1	1	1	Complement carry
DAA	0	0	1	0	0	1	1	1	Decimal adjust A
CONTROL									
EI	1	1	1	1	1	0	1	1	Enable Interrupts
DI	1	1	1	1	0	0	1	1	Disable Interrupt
NOP	0	0	0	0	0	0	0	0	No-operation
HLT	0	1	1	1	0	1	1	0	Halt
NEW 8085A INSTRUCTIONS									
RIM	0	0	1	0	0	0	0	0	Read Interrupt Mask
SIM	0	0	1	1	0	0	0	0	Set Interrupt Mask

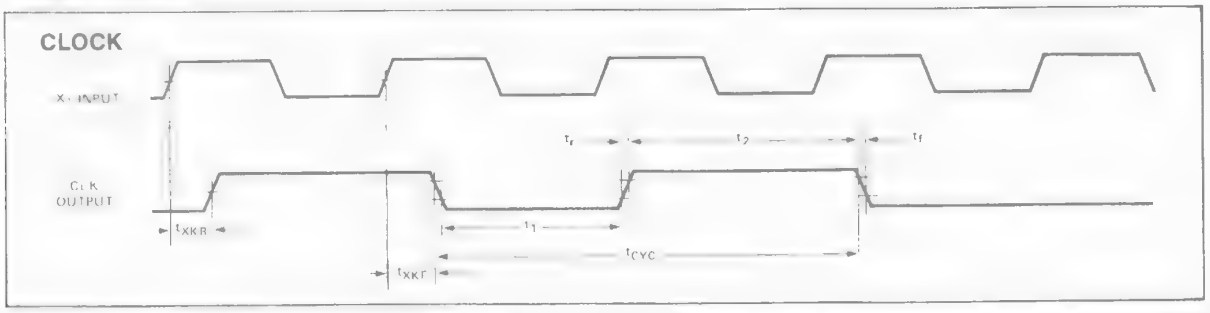
NOTES:

1. DDS or SSS: B 000, C 001, D 010, E011, H 100, L 101, Memory 110, A 111.
2. Two possible cycle times (6/12) indicate instruction cycles dependent on condition flags.

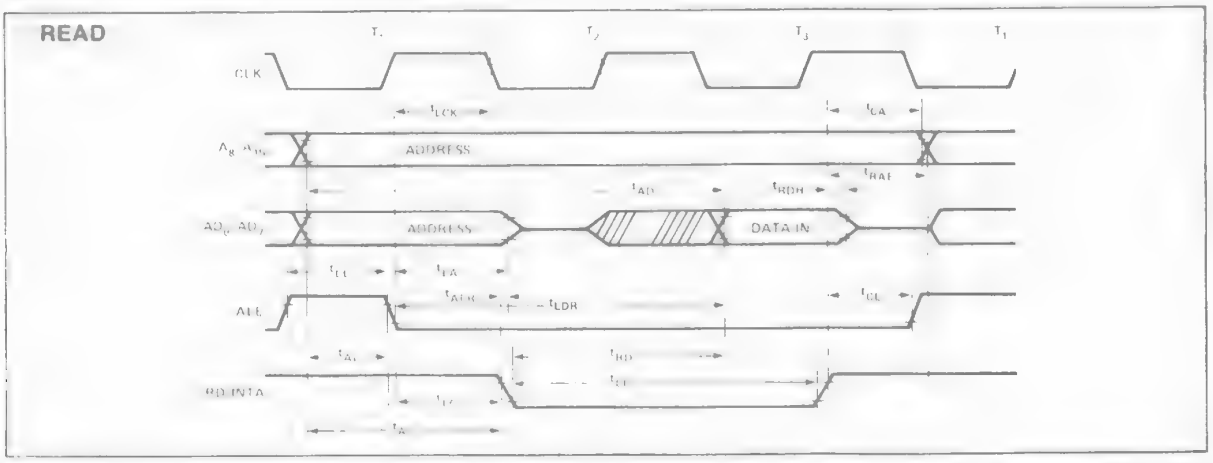
*All mnemonics copyrighted ©Intel Corporation 1976.

WAVEFORMS

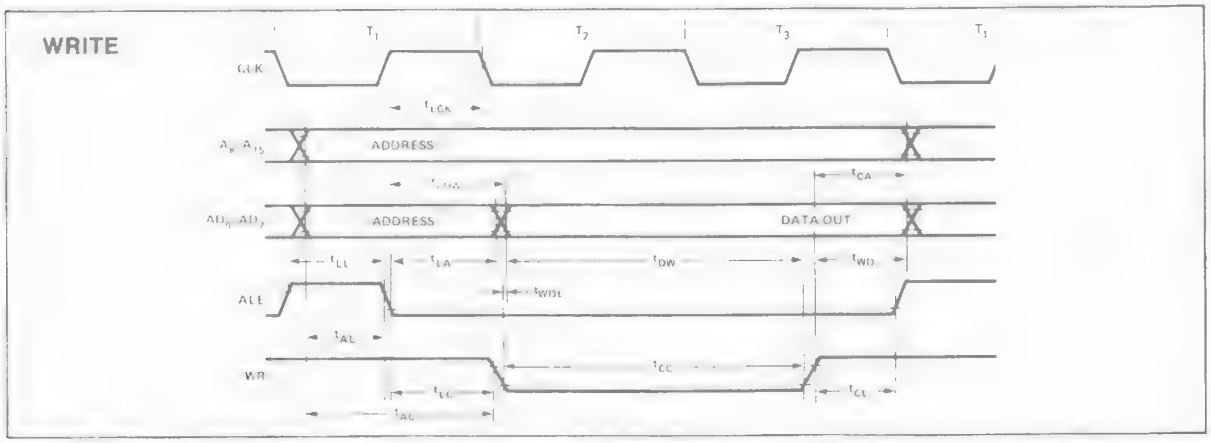
CLOCK



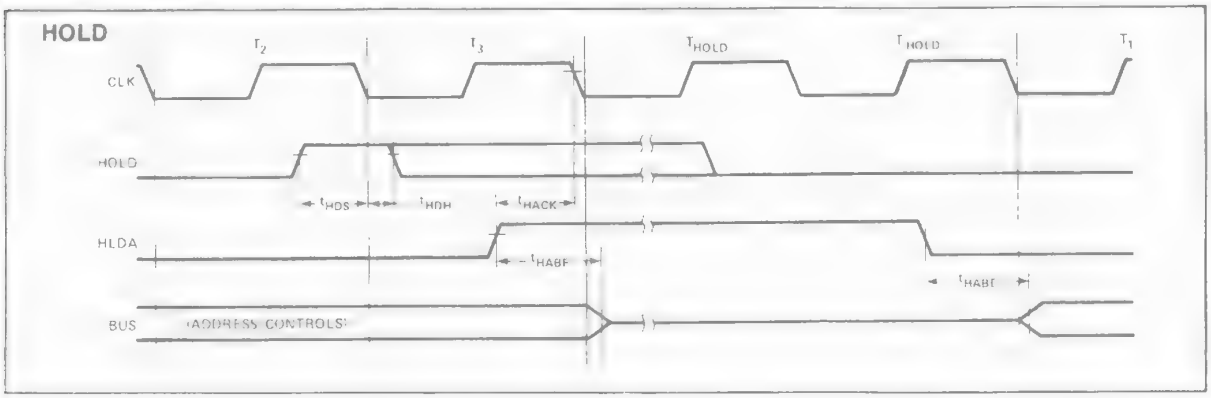
READ



WRITE



HOLD



8085A/8085A-2
SINGLE CHIP 8-BIT N-CHANNEL MICROPROCESSORS

- **Single +5V Power Supply**
- **100% Software Compatible with 8080A**
- **1.3 μs Instruction Cycle (8085A); 0.8 μs (8085A-2)**
- **On-Chip Clock Generator (with External Crystal, LC or RC Network)**
- **On-Chip System Controller; Advanced Cycle Status Information Available for Large System Control**
- **Four Vectored Interrupt Inputs (One is Non-Maskable) Plus an 8080A-Compatible Interrupt**
- **Serial In/Serial Out Port**
- **Decimal, Binary and Double Precision Arithmetic**
- **Direct Addressing Capability to 64k Bytes of Memory**

The Intel® 8085A is a complete 8 bit parallel Central Processing Unit (CPU). Its instruction set is 100% software compatible with the 8080A microprocessor, and it is designed to improve the present 8080A's performance by higher system speed. Its high level of system integration allows a minimum system of three IC's [8085A CPU, 8156 RAM/IO and 8355/8755A (ROM/PROM/IO)] while maintaining total system expandability. The 8085A-2 is a faster version of the 8085A.

The 8085A incorporates all of the features that the 8224 (clock generator) and 8228 (system controller) provided for the 8080A, thereby offering a high level of system integration.

The 8085A uses a multiplexed data bus. The address is split between the 8 bit address bus and the 8 bit data bus. The on-chip address latches of 8155/8156/8355/8755A memory products allow a direct interface with the 8085A.

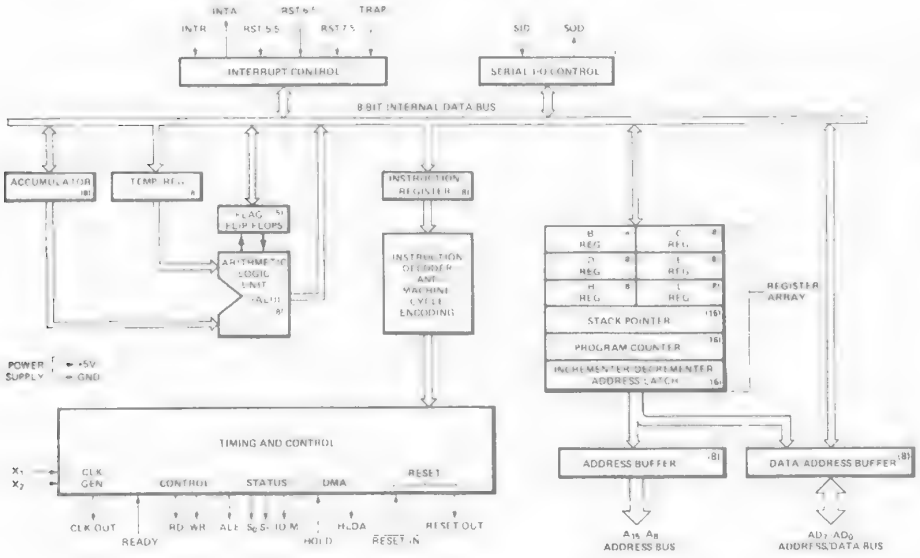


Figure 1. 8085A CPU Functional Block Diagram

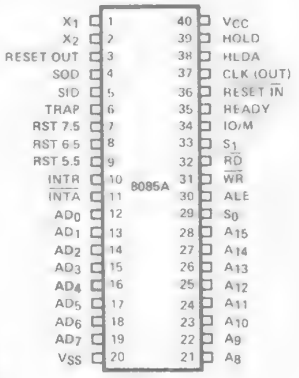


Figure 2. 8085A Pin Configuration

AFN-01242C

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias. . . . . 0°C to 70°C
Storage Temperature . . . . . .–65°C to +150°C
Voltage on Any Pin
With Respect to Ground . . . . . –0.5V to +7V
Power Dissipation . . . . . 1.5 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 0V ±5%, V_{SS} = 0V; unless otherwise specified)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	-0.5	+0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC}+0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = -400μA
I_{CC}	Power Supply Current		170	mA	
I_{IL}	Input Leakage		±10	μA	$0 \leq V_{IN} \leq V_{CC}$
I_{LO}	Output Leakage		±10	μA	$0.45V \leq V_{out} \leq V_{CC}$
V_{ILR}	Input Low Level, RESET	-0.5	+0.8	V	
V_{IHR}	Input High Level, RESET	2.4	V_{CC} +0.5	V	
V_{HY}	Hysteresis, RESET	0.25		V	

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 0V ±5%, V_{SS} = 0V)

Symbol	Parameter	8085A[2]		8085A-2[2]		Units
		Min.	Max.	Min.	Max.	
t_{CYC}	CLK Cycle Period	320	2000	200	2000	ns
t_1	CLK Low Time (Standard CLK Loading)	80		40		ns
t_2	CLK High Time (Standard CLK Loading)	120		70		ns
t_r, t_f	CLK Rise and Fall Time		30		30	ns
t_{XKR}	X_1 Rising to CLK Rising	30	120	30	100	ns
t_{XKF}	X_1 Rising to CLK Falling	30	150	30	110	ns
t_{AC}	A_{8-15} Valid to Leading Edge of Control[1]	270		115		ns
t_{ACL}	A_{0-7} Valid to Leading Edge of Control	240		115		ns
t_{AD}	A_{0-15} Valid to Valid Data In		575		350	ns
t_{AFR}	Address Float After Leading Edge of $\overline{READ}$ ($\overline{INTA}$)		0		0	ns
t_{AL}	A_{8-15} Valid Before Trailing Edge of ALE[1]	115		50		ns
t_{ALL}	A_{0-7} Valid Before Trailing Edge of ALE	90		50		ns
t_{ARY}	READY Valid from Address Valid		220		100	ns
t_{CA}	Address (A_{8-15}) Valid After Control	120		60		ns
t_{CC}	Width of Control Low ($\overline{RD}$, $\overline{WR}$, $\overline{INTA}$) Edge of ALE	400		230		ns
t_{CL}	Trailing Edge of Control to Leading Edge of ALE	50		25		ns
t_{DW}	Data Valid to Trailing Edge of $\overline{WRITE}$	420		230		ns
t_{HABE}	HLDA to Bus Enable		210		150	ns
t_{HABF}	Bus Float After HLDA		210		150	ns
t_{HACK}	HLDA Valid to Trailing Edge of CLK	110		40		ns
t_{HDH}	HOLD Hold Time	0		0		ns
t_{HDS}	HOLD Setup Time to Trailing Edge of CLK	170		120		ns
t_{INH}	INTR Hold Time	0		0		ns
t_{INS}	INTR, RST, and TRAP Setup Time to Falling Edge of CLK	160		150		ns
t_{LA}	Address Hold Time After ALE	100		50		ns
t_{LC}	Trailing Edge of ALE to Leading Edge of Control	130		60		ns
t_{LCK}	ALE Low During CLK High	100		50		ns
t_{LDR}	ALE to Valid Data During Read		460		270	ns
t_{LDW}	ALE to Valid Data During Write		200		120	ns
t_{LL}	ALE Width	140		80		ns
t_{LRY}	ALE to READY Stable		110		30	ns

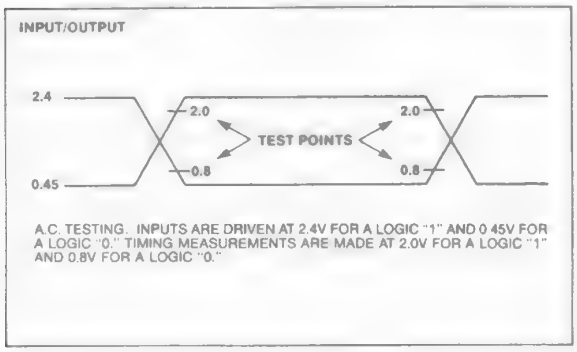
A.C. CHARACTERISTICS (Continued)

Symbol	Parameter	8085A[2]		8085A-2[2]		Units
		Min.	Max.	Min.	Max.	
t_{RAE}	Trailing Edge of $\overline{READ}$ to Re-Enabling of Address	150		90		ns
t_{RD}	$\overline{READ}$ (or $\overline{INTA}$) to Valid Data		300		150	ns
t_{RV}	Control Trailing Edge to Leading Edge of Next Control	400		220		ns
t_{RDH}	Data Hold Time After $\overline{READ}$ $\overline{INTA}$[7]	0		0		ns
t_{RYH}	READY Hold Time	0		0		ns
t_{RYS}	READY Setup Time to Leading Edge of CLK	110		100		ns
t_{WD}	Data Valid After Trailing Edge of $\overline{WRITE}$	100		[illegible]		ns
t_{WDL}	LEADING Edge of WRITE to Data Valid		40		20	ns

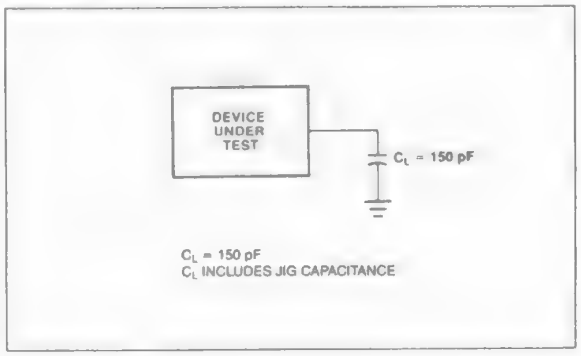
NOTES:

1. A_8-A_{15} address Specs apply to IO/$\overline{M}$, S_0, and S_1 except A_8-A_{15} are undefined during T_4-T_6 of OF cycle whereas IO/$\overline{M}$, S_0, and S_1 are stable.
2. Test conditions: $t_{CYC} = 320$ ns (8085A)/200 ns (8085A-2); $C_L = 150$ pF.
3. For all output timing where $C_L = 150$ pF use the following correction factors:
   $25\,pF \leq C_L < 150\,pF$: -0.10 ns/pF
   $150\,pF < C_L \leq 300\,pF$: $+0.30$ ns/pF
4. Output timings are measured with purely capacitive load.
5. All timings are measured at output votage $V_L = 0.8V$, $V_H = 2.0V$, and 1.5V with 20 ns rise and fall time on inputs.
6. To calculate timing specifications at other values of t_{CYC} use Table 7.
7. Data hold time is guaranteed under all loading conditions.

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING LOAD CIRCUIT



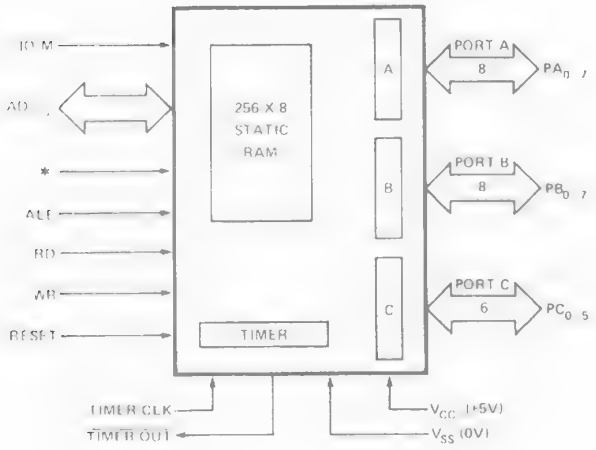
8155H/8156H/8155H-2/8156H-2
2048-BIT STATIC HMOS RAM WITH I/O PORTS AND TIMER

- Single +5V Power Supply with 10% Voltage Margins
- 30% Lower Power Consumption than the 8155 and 8156
- 100% Compatible with 8155 and 8156
- 256 Word x 8 Bits
- Completely Static Operation
- Internal Address Latch
- 2 Programmable 8-Bit I/O Ports
- 1 Programmable 6-Bit I/O Port
- Programmable 14-Bit Binary Counter/Timer
- Compatible with 8085AH, 8085A and 8088 CPU
- Multiplexed Address and Data Bus
- Available in EXPRESS
  - Standard Temperature Range
  - Extended Temperature Range

The Intel® 8155H and 8156H are RAM and I/O chips implemented in N-Channel, depletion load, silicon gate technology (HMOS), to be used in the 8085AH and 8088 microprocessor systems. The RAM portion is designed with 2048 static cells organized as 256 x 8. They have a maximum access time of 400 ns to permit use with no wait states in 8085AH CPU.The 8155H-2 and 8156H-2 have maximum access times of 330 ns for use with the 8085AH-2 and the 5 MHz 8088 CPU.

The I/O portion consists of three general purpose I/O ports. One of the three ports can be programmed to be status pins, thus allowing the other two ports to operate in handshake mode.

A 14-bit programmable counter/timer is also included on chip to provide either a square wave or terminal count pulse for the CPU system depending on timer mode.



*8155H/8155H-2 = $\overline{CE}$, 8156H/8156H-2 = CE

Figure 1. Block Diagram

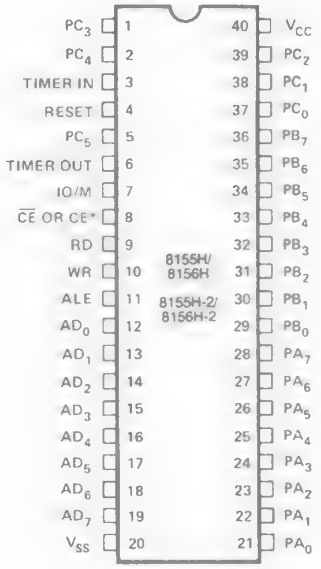


Figure 2. Pin Configuration

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Table 1. Pin Description

Symbol	Type	Name and Function
RESET	I	**Reset:** Pulse provided by the 8085AH to initialize the system (connect to 8085AH RESET OUT). Input high on this line resets the chip and initializes the three I/O ports to input mode. The width of RESET pulse should typically be two 8085AH clock cycle times.
AD_{0-7}	I/O	**Address/Data:** 3-state Address/Data lines that interface with the CPU lower 8-bit Address/Data Bus. The 8-bit address is latched into the address latch inside the 8155H/56H on the falling edge of ALE. The address can be either for the memory section or the I/O section depending on the IO/$\overline{M}$ input. The 8-bit data is either written into the chip or read from the chip, depending on the $\overline{WR}$ or $\overline{RD}$ input signal.
CE or $\overline{CE}$	I	**Chip Enable:** On the 8155H, this pin is $\overline{CE}$ and is ACTIVE LOW. On the 8156H, this pin is CE and is ACTIVE HIGH.
$\overline{RD}$	I	**Read Control:** Input low on this line with the Chip Enable active enables and AD_{0-7} buffers. If IO/$\overline{M}$ pin is low, the RAM content will be read out to the AD bus. Otherwise the content of the selected I/O port or command/status registers will be read to the AD bus.
$\overline{WR}$	I	**Write Control:** Input low on this line with the Chip Enable active causes the data on the Address/Data bus to be written to the RAM or I/O ports and command/status register, depending on IO/$\overline{M}$.
ALE	I	**Address Latch Enable:** This control signal latches both the address on the AD_{0-7} lines and the state of the Chip Enable and IO/$\overline{M}$ into the chip at the falling edge of ALE
IO/$\overline{M}$	I	**I/O Memory:** Selects memory if low and I/O and command/status registers if high.
PA_{0-7}(8)	I/O	**Port A:** These 8 pins are general purpose I/O pins. The in/out direction is selected by programming the command register.
PB_{0-7}(8)	I/O	**Port B:** These 8 pins are general purpose I/O pins. The in/out direction is selected by programming the command register
PC_{0-5}(6)	I/O	**Port C:** These 6 pins can function as either input port, output port, or as control signals for PA and PB. Programming is done through the command register. When PC_{0-5} are used as control signals, they will provide the following: PC_0 — A INTR (Port A Interrupt) PC_1 — ABF (Port A Buffer Full) PC_2 — $\overline{A\ STB}$ (Port A Strobe) PC_3 — B INTR (Port B Interrupt) PC_4 — B BF (Port B Buffer Full) PC_5 — $\overline{B\ STB}$ (Port B Strobe)
TIMER IN	I	**Timer Input:** Input to the counter-timer.
$\overline{TIMER\ OUT}$	O	**Timer Output:** This output can be either a square wave or a pulse, depending on the timer mode.
V_{CC}		**Voltage:** +5 volt supply.
V_{SS}		**Ground:** Ground reference.

FUNCTIONAL DESCRIPTION

The 8155H/8156H contains the following:

- 2k Bit Static RAM organized as 256 x 8
- Two 8-bit I/O ports (PA & PB) and one 6-bit I/O port (PC)
- 14-bit timer-counter

The IO/$\overline{M}$ (IO/Memory Select) pin selects either the five registers (Command, Status, PA_{0-7}, PB_{0-7}, PC_{0-5}) or the memory (RAM) portion.

The 8-bit address on the Address/Data lines, Chip Enable input CE or $\overline{CE}$, and IO/$\overline{M}$ are all latched on-chip at the falling edge of ALE.

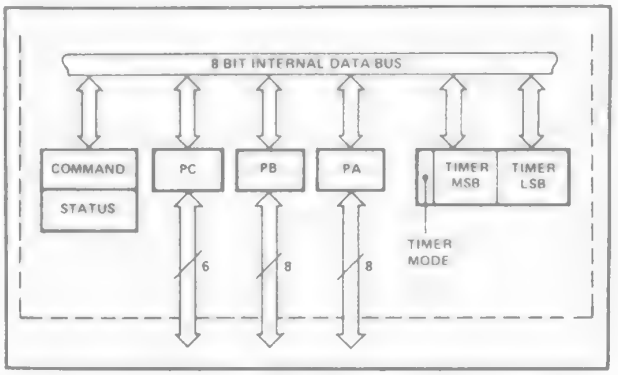


Figure 3. 8155H/8156H Internal Registers

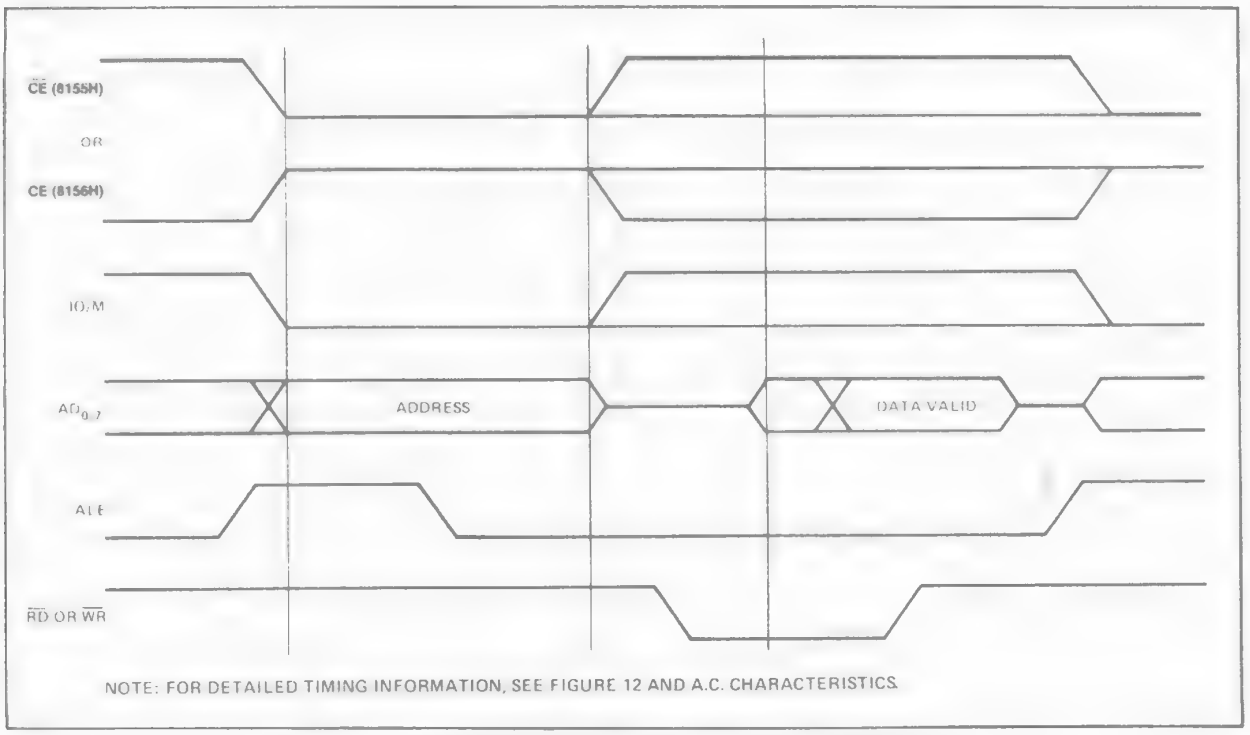


Figure 4. 8155H/8156H On-Board Memory Read/Write Cycle

PROGRAMMING OF THE COMMAND REGISTER

The command register consists of eight latches. Four bits (0-3) define the mode of the ports, two bits (4-5) enable or disable the interrupt from port C when it acts as control port, and the last two bits (6-7) are for the timer.

The command register contents can be altered at any time by using the I/O address XXXXX000 during a WRITE operation with the Chip Enable active and IO/$\overline{M}$ = 1. The meaning of each bit of the command byte is defined in Figure 5. The contents of the command register may never be read.

READING THE STATUS REGISTER

The status register consists of seven latches, one for each bit; six (0-5) for the status of the ports and one (6) for the status of the timer.

The status of the timer and the I/O section can be polled by reading the Status Register (Address XXXXX000). Status word format is shown in Figure 6. Note that you may never write to the status register since the command register shares the same I/O address and the command register is selected when a write to that address is issued.

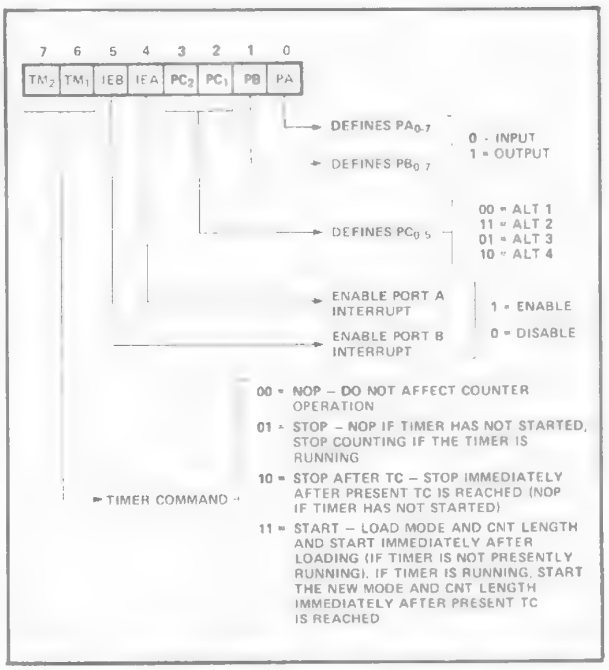


Figure 5. Command Register Bit Assignment

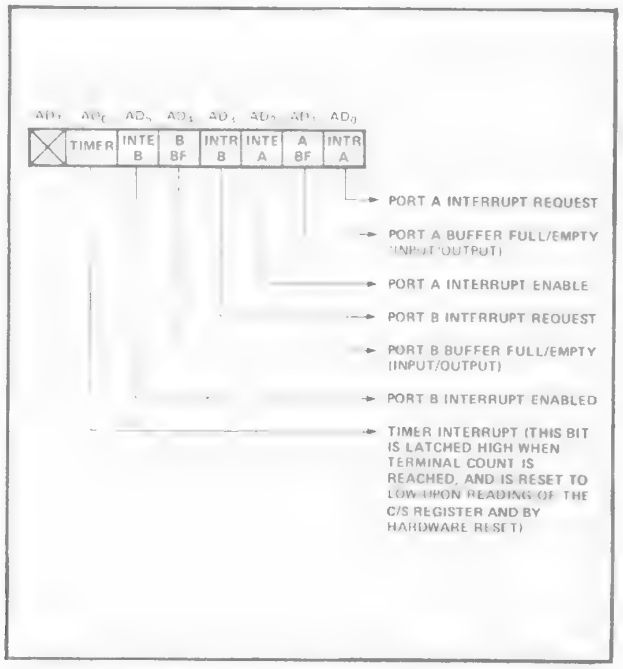


Figure 6. Status Register Bit Assignment

INPUT/OUTPUT SECTION

The I/O section of the 8155H/8156H consists of five registers: (See Figure 7.)

- **Command/Status Register (C/S)** — Both registers are assigned the address XXXXX000. The C/S address serves the dual purpose.

  When the C/S registers are selected during WRITE operation, a command is written into the command register. The contents of this register are *not* accessible through the pins.

  When the C/S (XXXXX000) is selected during a READ operation, the status information of the I/O ports and the timer becomes available on the AD_{0-7} lines

- **PA Register** — This register can be programmed to be either input or output ports depending on the status of the contents of the C/S Register. Also depending on the command, this port can operate in either the basic mode or the strobed mode (See timing diagram). The I/O pins assigned in relation to this register are PA_{0-7}. The address of this register is XXXXX001.

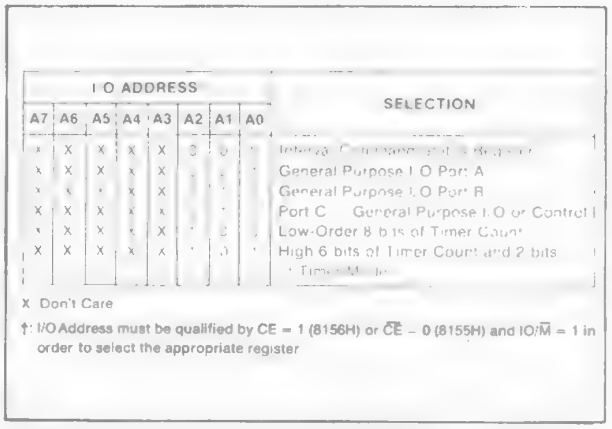
- **PB Register** — This register functions the same as PA Register. The I/O pins assigned are PB_{0-7}. The address of this register is XXXXX010.

- **PC Register** — This register has the address XXXXX011 and contains only 6 bits. The 6 bits can be programmed to be either input ports, output ports or as control signals for PA and PB by properly programming the AD_2 and AD_3 bits of the C/S register.

  When PC_{0-5} is used as a control port, 3 bits are assigned for Port A and 3 for Port B. The first bit is an interrupt that the 8155H sends out. The second is an output signal indicating whether the buffer is full or empty, and the third is an input pin to accept a strobe for the strobed input mode. (See Table 2.)

When the 'C' port is programmed to either ALT3 or ALT4, the control signals for PA and PB are initialized as follows:

CONTROL	INPUT MODE	OUTPUT MODE
BF	Low	Low
INTR	Low	High
STB	Input Control	Input Control



I/O ADDRESS								SELECTION
A7	A6	A5	A4	A3	A2	A1	A0	
X	X	X	X	X	0	0	0	Interrupt Command/Status Register
X	X	X	X	X	0	0	1	General Purpose I/O Port A
X	X	X	X	X	0	1	0	General Purpose I/O Port B
X	X	X	X	X	0	1	1	Port C General Purpose I/O or Control
X	X	X	X	X	1	0	0	Low-Order 8 bits of Timer Count
X	X	X	X	X	1	0	1	High 6 bits of Timer Count and 2 bits of Timer Mode

X Don't Care

†: I/O Address must be qualified by CE = 1 (8156H) or $\overline{CE}$ = 0 (8155H) and IO/$\overline{M}$ = 1 in order to select the appropriate register

Figure 7. I/O Port and Timer Addressing Scheme

Figure 8 shows how I/O PORTS A and B are structured within the 8155H and 8156H:

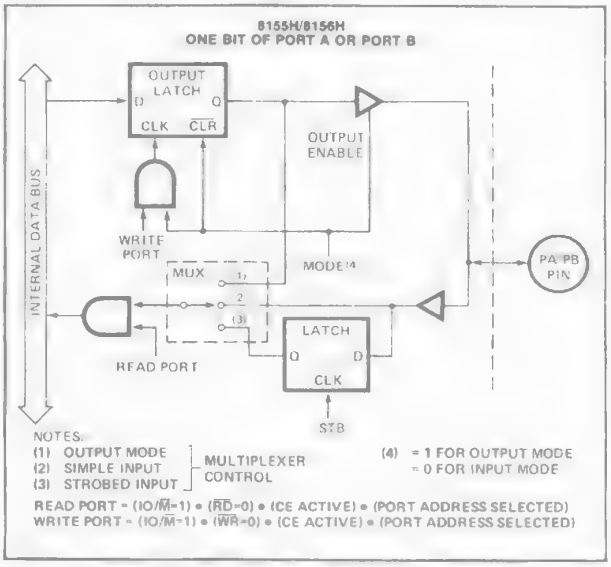


Figure 8. 8155H/8156H Port Functions

Table 2. Port Control Assignment

Pin	ALT 1	ALT 2	ALT 3	ALT 4
PC0	Input Port	Output Port	A INTR (Port A Interrupt)	A INTR (Port A Interrupt)
PC1	Input Port	Output Port	A BF (Port A Buffer Full)	A BF (Port A Buffer Full)
PC2	Input Port	Output Port	A $\overline{STB}$ (Port A Strobe)	A $\overline{STB}$ (Port A Strobe)
PC3	Input Port	Output Port	Output Port	B INTR (Port B Interrupt)
PC4	Input Port	Output Port	Output Port	B BF (Port B Buffer Full)
PC5	Input Port	Output Port	Output Port	B $\overline{STB}$ (Port B Strobe)

Note in the diagram that when the I/O ports are programmed to be output ports, the contents of the output ports can still be read by a READ operation when appropriately addressed.

The outputs of the 8155H/8156H are "glitch-free" meaning that you can write a "1" to a bit position that was previously "1" and the level at the output pin will not change.

Note also that the output latch is cleared when the port enters the input mode. The output latch cannot be loaded by writing to the port if the port is in the input mode. The result is that each time a port mode is changed from input to output, the output pins will go low. When the 8155H/56H is RESET, the output latches are all cleared and all 3 ports enter the input mode.

When in the ALT 1 or ALT 2 modes, the bits of PORT C are structured like the diagram above in the simple input or output mode, respectively.

Reading from an input port with nothing connected to the pins will provide unpredictable results.

Figure 9 shows how the 8155H/8156H I/O ports might be configured in a typical MCS-85 system.

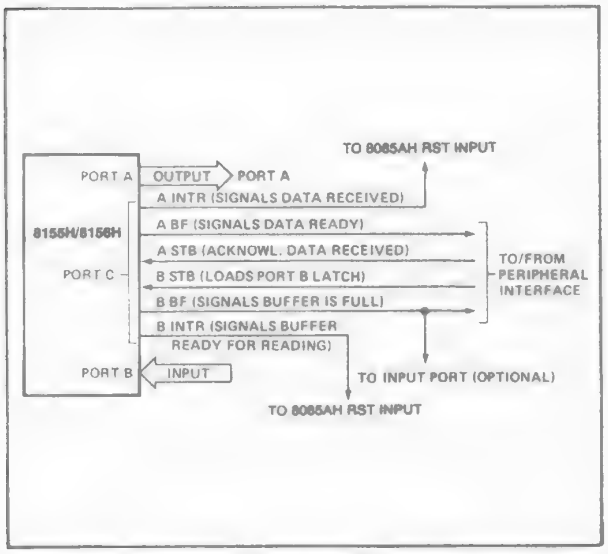


Figure 9. Example: Command Register = 00111001

TIMER SECTION

The timer is a 14-bit down-counter that counts the TIMER IN pulses and provides either a square wave or pulse when terminal count (TC) is reached.

The timer has the I/O address XXXXX100 for the low order byte of the register and the I/O address XXXXX101 for the high order byte of the register. (See Figure 7.)

To program the timer, the COUNT LENGTH REG is loaded first, one byte at a time, by selecting the timer addresses. Bits 0-13 of the high order count register will specify the length of the next count and bits 14-15 of the high order register will specify the timer output mode (see Figure 10). The value loaded into the count length register can have any value from 2H through 3FFH in Bits 0–13.

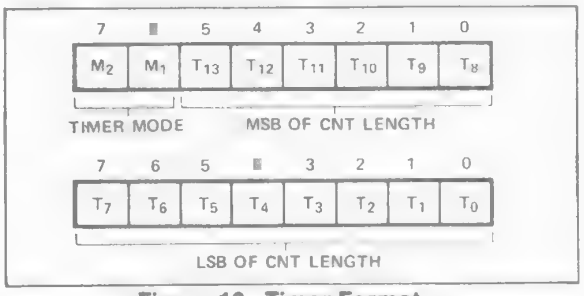


Figure 10. Timer Format

There are four modes to choose from: M2 and M1 define the timer mode, as shown in Figure 11.

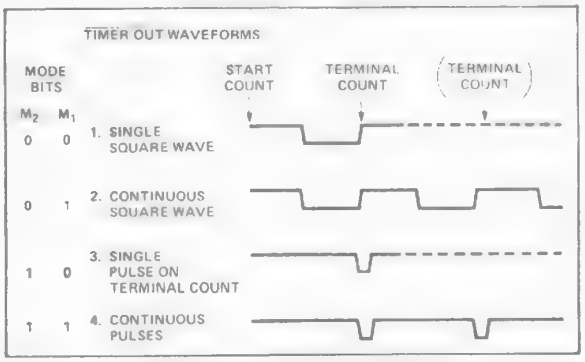


Figure 11. Timer Modes

Bits 6-7 (TM_2 and TM_1) of command register contents are used to start and stop the counter. There are four commands to choose from:

TM_2	TM_1	
0	0	NOP — Do not affect counter operation.
0	1	STOP — NOP if timer has not started; stop counting if the timer is running.
1	0	STOP AFTER TC — Stop immediately after present TC is reached (NOP if timer has not started)
1	1	START — Load mode and CNT length and start immediately after loading (if timer is not presently running). If timer is running, start the new mode and CNT length immediately after present TC is reached.

Note that while the counter is counting, you may load a new count and mode into the count length registers. Before the new count and mode will be used by the counter, you must issue a START command to the counter. This applies even though you may only want to change the count and use the previous mode.

In case of an odd-numbered count, the first half-cycle of the squarewave output, which is high, is one count longer than the second (low) half-cycle, as shown in Figure 12.

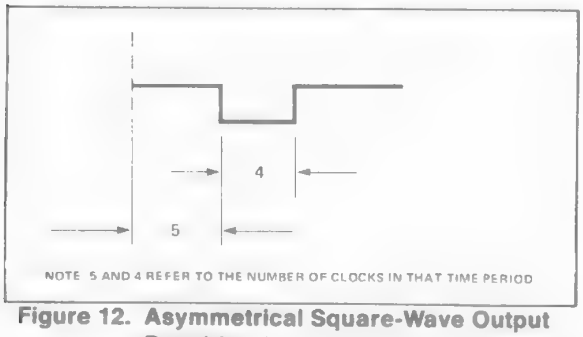


Figure 12. Asymmetrical Square-Wave Output Resulting from Count of 9

The counter in the 8155H is not initialized to any particular mode or count when hardware RESET occurs, but RESET does *stop* the counting. Therefore, counting cannot begin following RESET until a START command is issued via the C/S register.

Please note that the timer circuit on the 8155H/8156H chip is designed to be a square-wave timer, not an event counter. To achieve this, it counts down by twos twice in completing one cycle. Thus, its registers do not contain values directly representing the number of TIMER IN pulses received. You cannot load an initial value of 1 into the count register and cause the timer to operate, as its terminal count value is 10 (binary) or 2 (decimal). (For the detection of single pulses, it is suggested that one **of the hardware interrupt pins on the 8085AH be used.)** After the timer has started counting down, the values residing in the count registers can be used to calculate the actual number of TIMER IN pulses required to complete the timer cycle if desired. To obtain the remaining count, perform the following operations in order:

1. Stop the count
2. Read in the 16-bit value from the count length registers
3. Reset the upper two mode bits
4. Reset the carry and rotate right one position all 16 bits through carry
5. If carry is set, add 1/2 of the full original count (1/2 full count — 1 if full count is odd).

Note: If you started with an odd count and you read the count length register before the third count pulse occurs, you will not be able to discern whether one or two counts has occurred. Regardless of this, the 8155H/56H always counts out the right number of pulses in generating the TIMER OUT waveforms.

8085A MINIMUM SYSTEM CONFIGURATION

Figure 13a shows a minimum system using three chips, containing:

- 256 Bytes RAM
- 2K Bytes ROM
- 38 I/O Pins
- 1 Interval Timer
- 4 Interrupt Levels

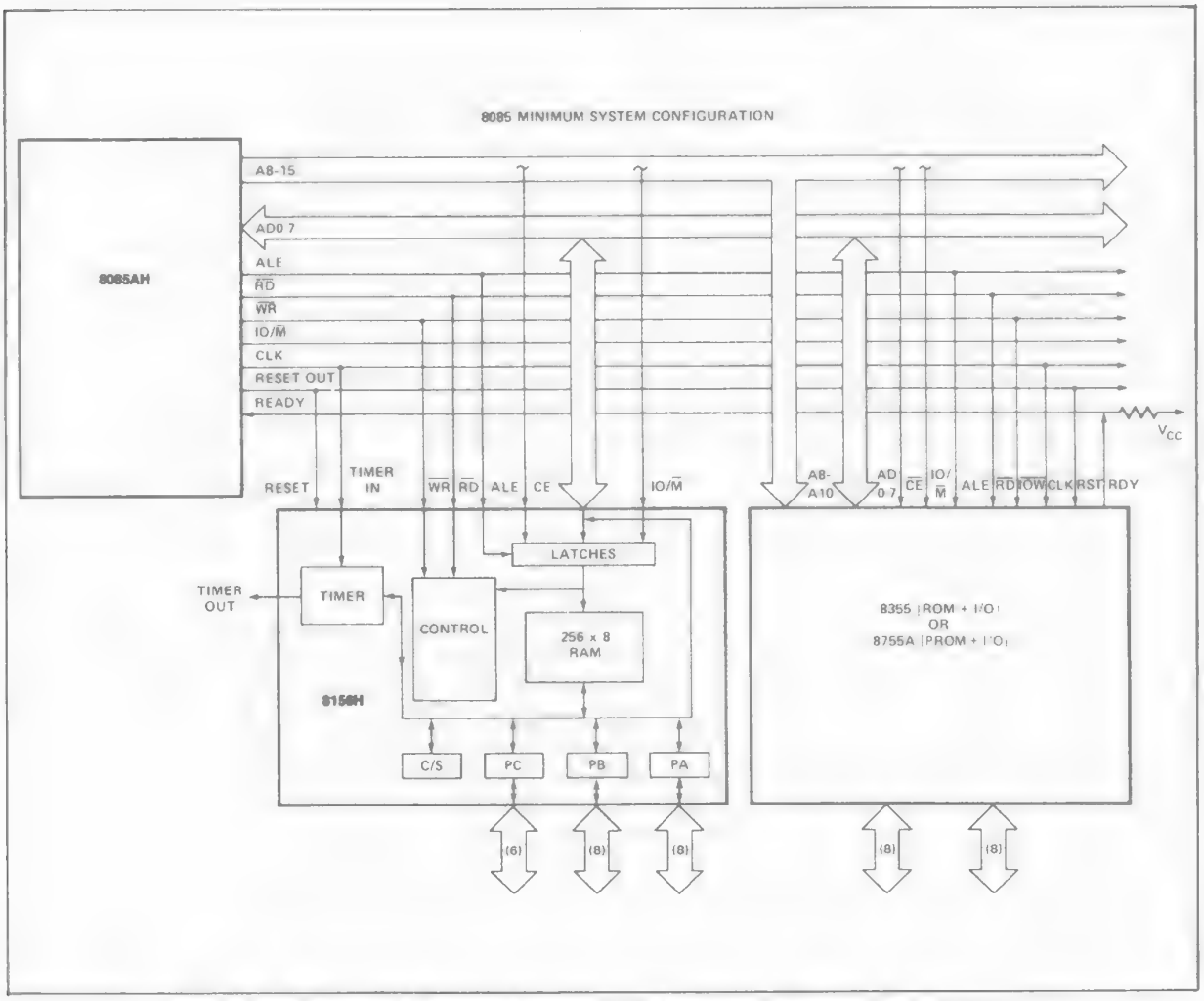


Figure 13a. 8085AH Minimum System Configuration (Memory Mapped I/O)

8088 FIVE CHIP SYSTEM

Figure 13b shows a five chip system containing:

- 1.25K Bytes RAM
- 2K Bytes ROM
- 38 I/O Pins
- 1 Interval Timer
- 2 Interrupt Levels

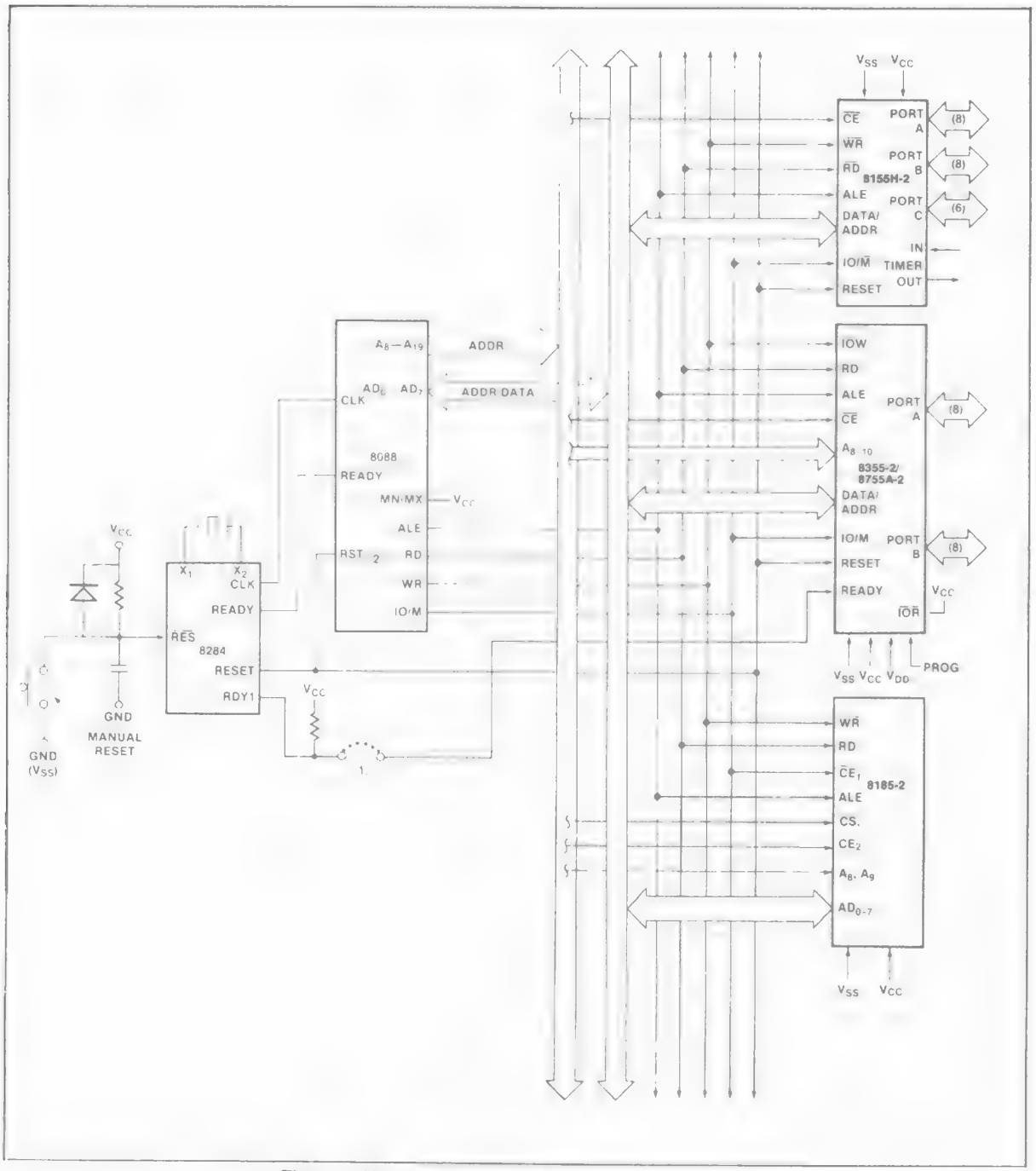


Figure 13b. 8088 Five Chip System Configuration

AFN-01960C

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... 0°C to +70°C
Storage Temperature ..... -65°C to +150°C
Voltage on Any Pin
With Respect to Ground ..... -0.5V to +7V
Power Dissipation 1.5W

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ± 10%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	-0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC}+0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = -400μA
I_{IL}	Input Leakage		±10	μA	$0V \leq V_{IN} \leq V_{CC}$
I_{LO}	Output Leakage Current		± 10	μA	$0.45V \leq V_{OUT} \leq V_{CC}$
I_{CC}	V_{CC} Supply Current		125	mA	
I_{IL}(CE)	Chip Enable Leakage 8155H 8156H		 +100 -100	 μA μA	$0V \leq V_{IN} \leq V_{CC}$

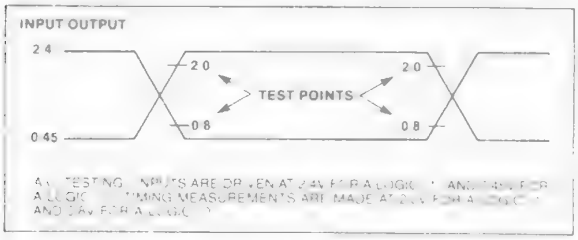
A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ±10%)

		8155H/8156H		8155H-2/8156H-2		
Symbol	Parameter	Min.	Max.	Min.	Max.	Units
t_{AL}	Address to Latch Set Up Time	50		30		ns
t_{LA}	Address Hold Time after Latch	80		30		ns
t_{LC}	Latch to READ/WRITE Control	100		40		ns
t_{RD}	Valid Data Out Delay from READ Control		170		140	ns
t_{AD}	Address Stable to Data Out Valid		400		330	ns
t_{LL}	Latch Enable Width	100		70		ns
t_{RDF}	Data Bus Float After READ	0	100	0	80	ns
t_{CL}	READ/WRITE Control to Latch Enable	20		10		ns
t_{CC}	READ/WRITE Control Width	250		200		ns
t_{DW}	Data In to WRITE Set Up Time	150		100		ns
t_{WD}	Data In Hold Time After WRITE	25		25		ns
t_{RV}	Recovery Time Between Controls	300		200		ns
t_{WP}	WRITE to Port Output		400		300	ns
t_{PR}	Port Input Setup Time	70		50		ns
t_{RP}	Port Input Hold Time	50		10		ns
t_{SBF}	Strobe to Buffer Full		400		300	ns
t_{SS}	Strobe Width	200		150		ns
t_{RBE}	READ to Buffer Empty		400		300	ns
t_{SI}	Strobe to INTR On		400		300	ns

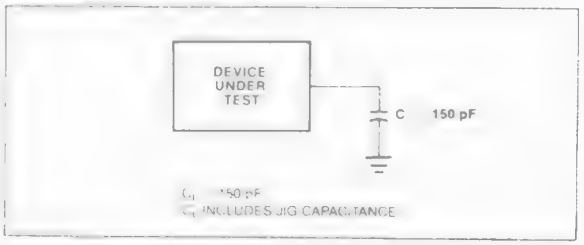
A.C. CHARACTERISTICS (Continued) (T_A = 0°C to 70°C, V_{CC} = 5V ±10%)

		8155H/8156H		8155H-2/8156H-2		
Symbol	**Parameter**	**Min.**	**Max.**	**Min.**	**Max.**	**Units**
t_{RDI}	READ to INTR Off		400		300	ns
t_{PSS}	Port Setup Time to Strobe Strobe	50		0		ns
t_{PHS}	Port Hold Time After Strobe	120		100		ns
t_{SBE}	Strobe to Buffer Empty		400		300	ns
t_{WBF}	WRITE to Buffer Full		400		300	ns
t_{WI}	WRITE to INTR Off		400		300	ns
t_{TL}	TIMER-IN to $\overline{\text{TIMER-OUT}}$ Low		400		300	ns
t_{TH}	TIMER-IN to $\overline{\text{TIMER-OUT}}$ High		400		300	ns
t_{RDE}	Data Bus Enable from READ Control	10		10		ns
t_1	TIMER-IN Low Time	80		40		ns
t_2	TIMER-IN High Time	120		70		ns

A.C. TESTING INPUT, OUTPUT WAVEFORM

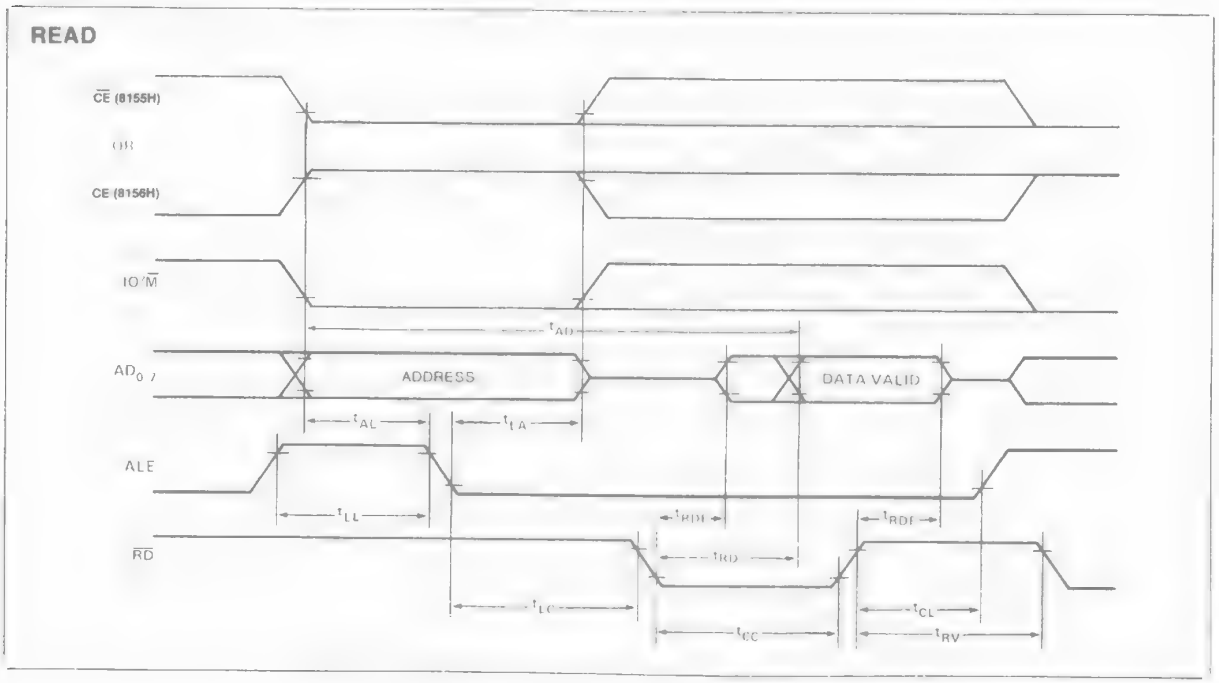


A.C. TESTING LOAD CIRCUIT



WAVEFORMS

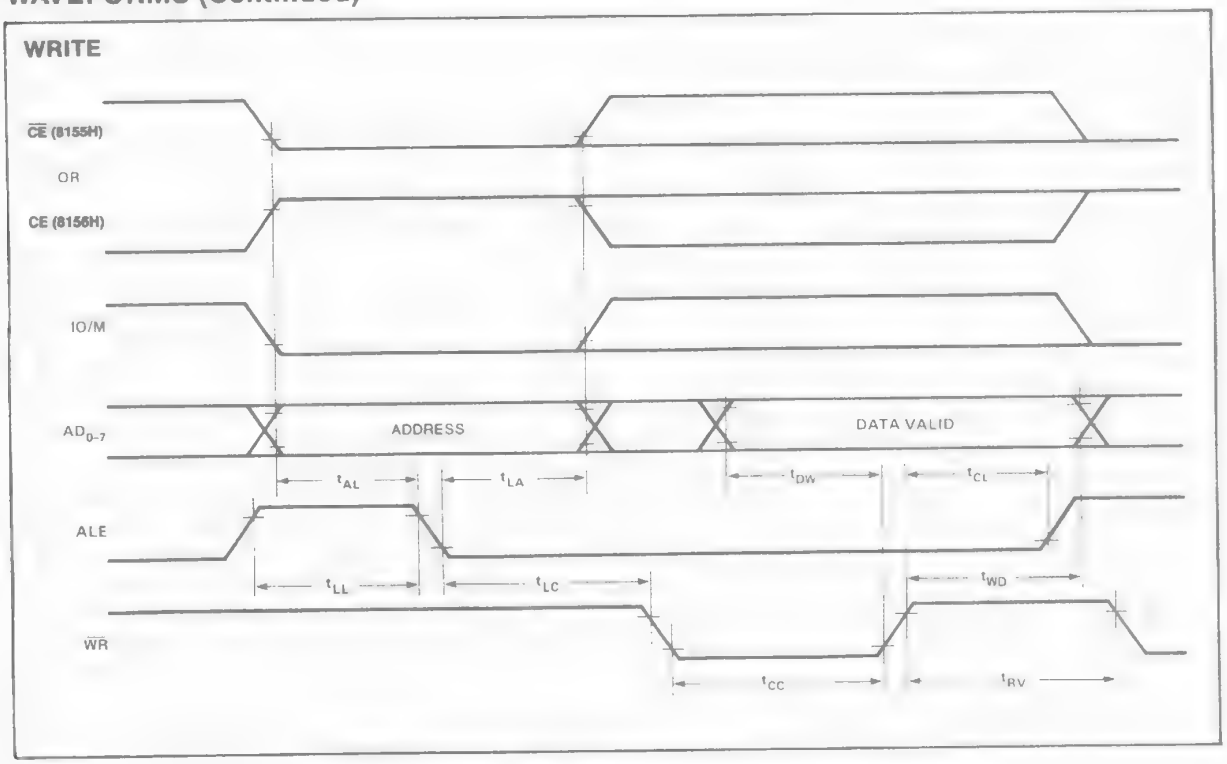
READ



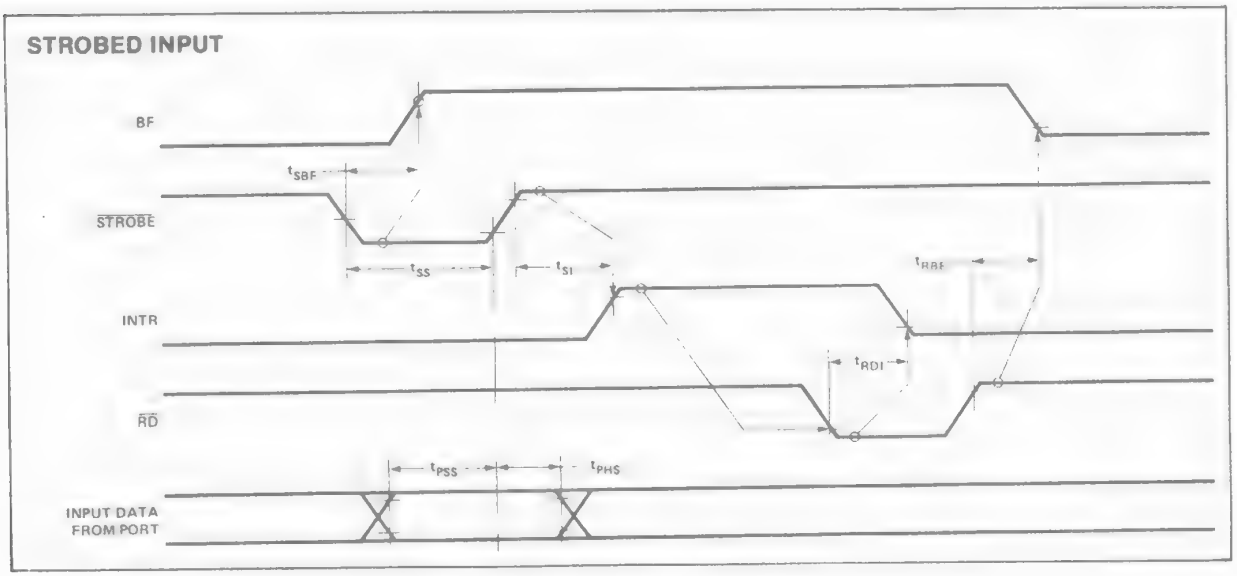
AFN-01960C

WAVEFORMS (Continued)

WRITE

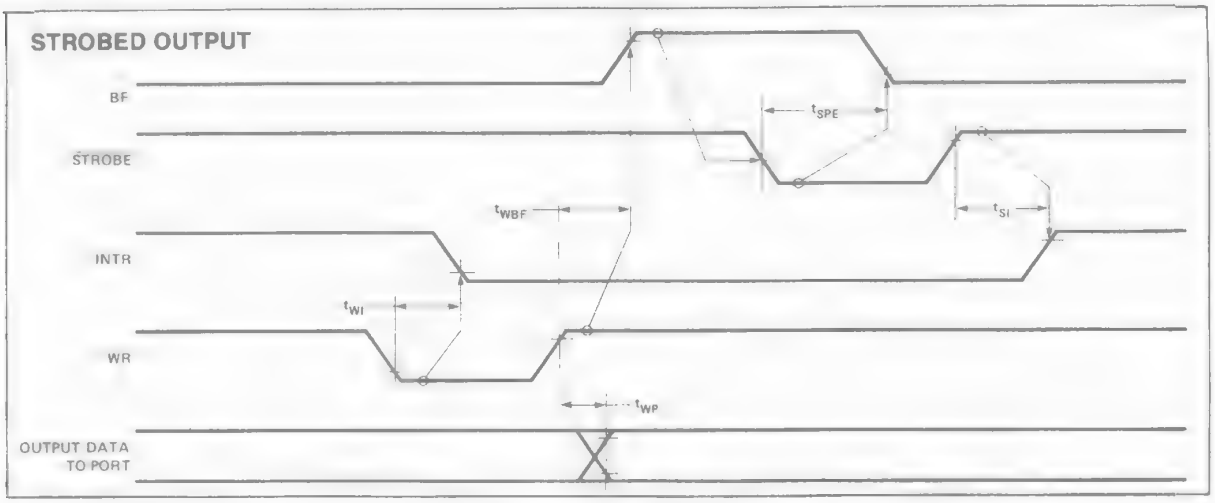


STROBED INPUT

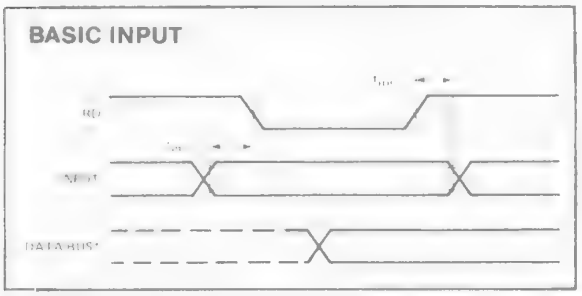


WAVEFORMS (Continued)

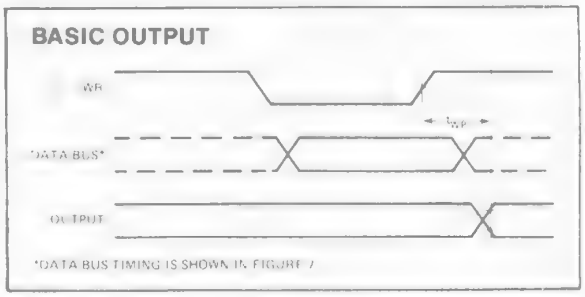
STROBED OUTPUT



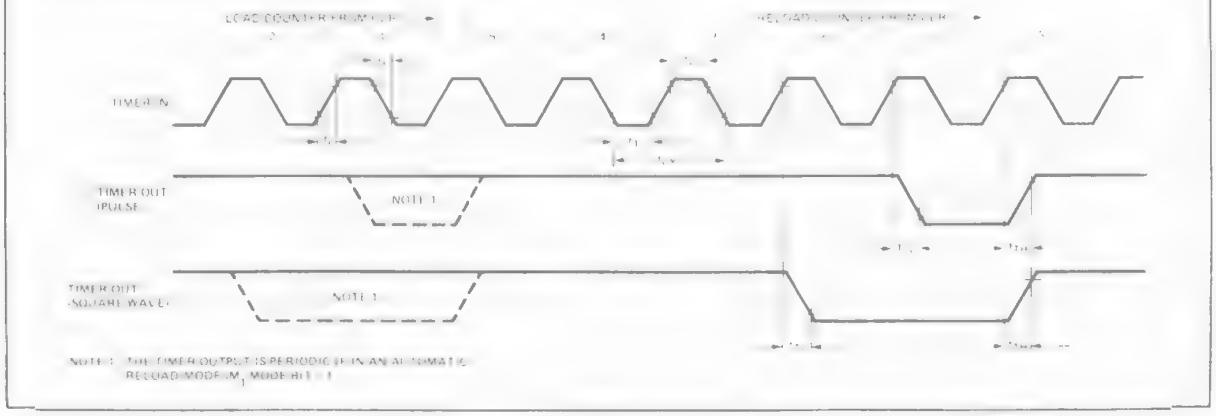
BASIC INPUT



BASIC OUTPUT



TIMER OUTPUT COUNTDOWN FROM 5 TO 1



8155/8156/8155-2/8156-2
2048 BIT STATIC MOS RAM WITH I/O PORTS AND TIMER

- 256 Word x 8 Bits
- Single +5V Power Supply
- Completely Static Operation
- Internal Address Latch
- 2 Programmable 8 Bit I/O Ports
- 1 Programmable 6-Bit I/O Port
- Programmable 14-Bit Binary Counter/Timer
- Compatible with 8085A and 8088 CPU
- Multiplexed Address and Data Bus
- 40 Pin DIP

The 8155 and 8156 are RAM and I/O chips to be used in the 8085A and 8088 microprocessor systems. The RAM portion is designed with 2048 static cells organized as 256 x 8. They have a maximum access time of 400 ns to permit use with no wait states in 8085A CPU. The 8155-2 and 8156-2 have maximum access times of 330 ns for use with the 8085A-2 and the 5 MHz 8088 CPU.

The I/O portion consists of three general purpose I/O ports. One of the three ports can be programmed to be status pins, thus allowing the other two ports to operate in handshake mode.

A 14-bit programmable counter/timer is also included on chip to provide either a square wave or terminal count pulse for the CPU system depending on timer mode.

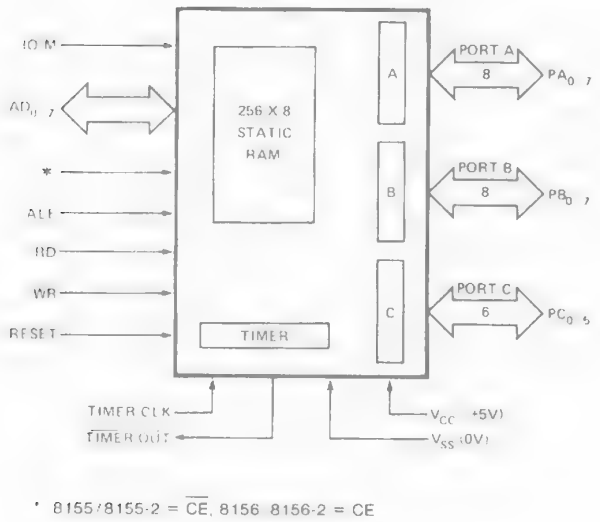


Figure 1. Block Diagram

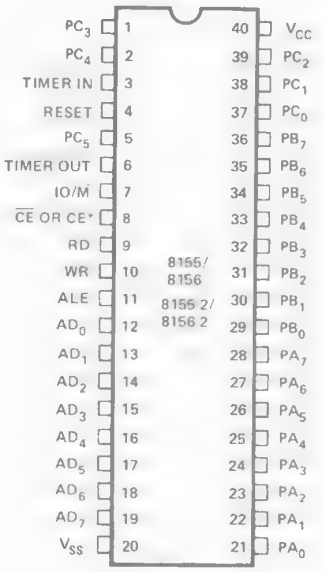


Figure 2. Pin Configuration

AFN-00201D

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... 0°C to +70°C
Storage Temperature ..... -65°C to +150°C
Voltage on Any Pin
With Respect to Ground ..... -0.5V to +7V
Power Dissipation 1.5W

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

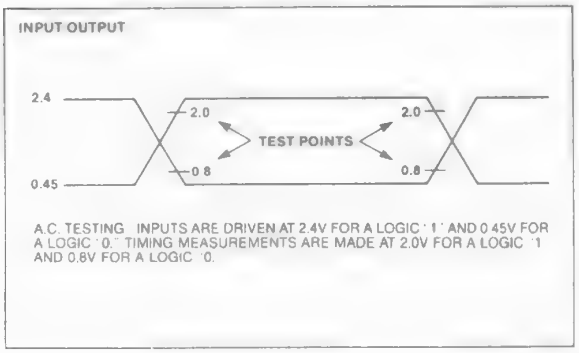
D.C. CHARACTERISTICS (T_A = 0°C to 70°C; V_{CC} = 5V ± 5%)

SYMBOL	PARAMETER	MIN.	MAX.	UNITS	TEST CONDITIONS
V_{IL}	Input Low Voltage	-0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC}+0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = -400μA
I_{IL}	Input Leakage		±10	μA	$0V \leq V_{IN} \leq V_{CC}$
I_{LO}	Output Leakage Current		± 10	μA	$0.45V \leq V_{OUT} \leq V_{CC}$
I_{CC}	V_{CC} Supply Current		180	mA	
I_{IL}(CE)	Chip Enable Leakage 8155 8156		 +100 -100	 μA μA	$0V \leq V_{IN} \leq V_{CC}$

A.C. CHARACTERISTICS (T_A = 0°C to 70°C; V_{CC} = 5V ± 5%)

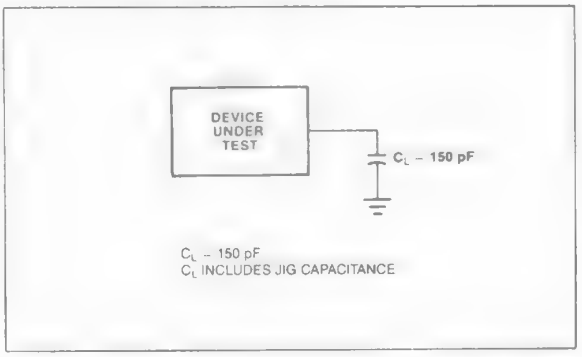
		8155/8156		8155-2/8156-2		
SYMBOL	PARAMETER	MIN.	MAX.	MIN.	MAX.	UNITS
t_{AL}	Address to Latch Set Up Time	50		30		ns
t_{LA}	Address Hold Time after Latch	80		30		ns
t_{LC}	Latch to READ/WRITE Control	100		40		ns
t_{RD}	Valid Data Out Delay from READ Control		170		140	ns
t_{AD}	Address Stable to Data Out Valid		400		330	ns
t_{LL}	Latch Enable Width	100		70		ns
t_{RDF}	Data Bus Float After READ	0	100	0	80	ns
t_{CL}	READ/WRITE Control to Latch Enable	20		10		ns
t_{CC}	READ/WRITE Control Width	250		200		ns
t_{DW}	Data In to WRITE Set Up Time	150		100		ns
t_{WD}	Data In Hold Time After WRITE	25		25		ns
t_{RV}	Recovery Time Between Controls	300		200		ns
t_{WP}	WRITE to Port Output		400		300	ns
t_{PR}	Port Input Setup Time	70		50		ns
t_{RP}	Port Input Hold Time	50		10		ns
t_{SBF}	Strobe to Buffer Full		400		300	ns
t_{SS}	Strobe Width	200		150		ns
t_{RBE}	READ to Buffer Empty		400		300	ns
t_{SI}	Strobe to INTR On		400		300	ns
t_{RDI}	READ to INTR Off		400		300	ns
t_{PSS}	Port Setup Time to Strobe Strobe	50		0		ns
t_{PHS}	Port Hold Time After Strobe	120		100		ns
t_{SBE}	Strobe to Buffer Empty		400		300	ns
t_{WBF}	WRITE to Buffer Full		400		300	ns
t_{WI}	WRITE to INTR Off		400		300	ns
t_{TL}	TIMER-IN to $\overline{\text{TIMER-OUT}}$ Low		400		300	ns
t_{TH}	TIMER-IN to $\overline{\text{TIMER-OUT}}$ High		400		300	ns
t_{RDE}	Data Bus Enable from READ Control	10		10		ns
t_1	TIMER-IN Low Time	80		40		ns
t_2	TIMER-IN High Time	120		70		ns

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING: INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0." TIMING MEASUREMENTS ARE MADE AT 2.0V FOR A LOGIC "1" AND 0.8V FOR A LOGIC "0.

A.C. TESTING LOAD CIRCUIT



AFN-00201D

8185/8185-2
1024 x 8-BIT STATIC RAM FOR MCS-85®

- **Multiplexed Address and Data Bus**
- **Directly Compatible with 8085A and iAPX 88 Microprocessors**
- **Low Operating Power Dissipation**
- **Low Standby Power Dissipation**
- **Single +5V Supply**
- **High Density 18-Pin Package**

The Intel® 8185 is an 8192-bit static random access memory (RAM) organized as 1024 words by 8-bits using N-channel Silicon-Gate MOS technology. The multiplexed address and data bus allows the 8185 to interface directly to the 8085A and iAPX 88 microprocessors to provide a maximum level of system integration.

The low standby power dissipation minimizes system power requirements when the 8185 is disabled.

The 8185-2 is a high-speed selected version of the 8185 that is compatible with the 5 MHz 8085A-2 and the 5 MHz iAPX 88.

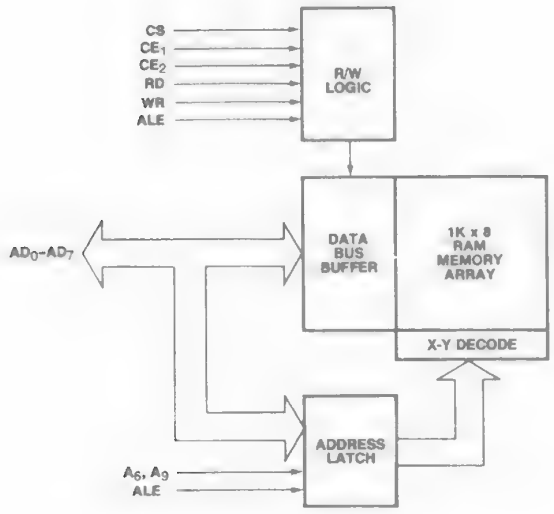
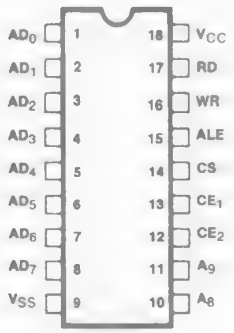


Figure 1. Block Diagram



AD_0–AD_7	ADDRESS/DATA LINES
A_8, A_9	ADDRESS LINES
CS	CHIP SELECT
CE_1	CHIP ENABLE (IO/M)
CE_2	CHIP ENABLE
ALE	ADDRESS LATCH ENABLE
WR	WRITE ENABLE

Figure 2. Pin Configuration

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AFN-01230C

FUNCTIONAL DESCRIPTION

The 8185 has been designed to provide for direct interface to the multiplexed bus structure and bus timing of the 8085A microprocessor.

At the beginning of an 8185 memory access cycle, the 8-bit address on AD_{0-7}, A_8 and A_9, and the status of $\overline{CE_1}$ and CE_2 are all latched internally in the 8185 by the falling edge of ALE. If the latched status of both $\overline{CE_1}$ and CE_2 are active, the 8185 powers itself up, but no action occurs until the $\overline{CS}$ line goes low and the appropriate $\overline{RD}$ or $\overline{WR}$ control signal input is activated.

The $\overline{CS}$ input is not latched by the 8185 in order to allow the maximum amount of time for address decoding in selecting the 8185 chip. Maximum power consumption savings will occur, however, only when $\overline{CE_1}$ and CE_2 are activated selectively to power down the 8185 when it is not in use. A possible connection would be to wire the 8085A's IO/$\overline{M}$ line to the 8185's $\overline{CE_1}$ input, thereby keeping the 8185 powered down during I/O and interrupt cycles.

Table 1.
Truth Table for
Power Down and Function Enable

$\overline{CE_1}$	CE_2	$\overline{CS}$	(CS*)[2]	8185 Status
1	X	X	0	Power Down and Function Disable[1]
X	0	X	0	Power Down and Function Disable[1]
0	1	1	0	Powered Up and Function Disable[1]
0	1	0	1	Powered Up and Enabled

NOTES:
X: Don't Care.
1: Function Disable implies Data Bus in high impedance state and not writing.
2: $CS^* = (\overline{CE_1} = 0) \bullet (CE_2 = 1) \bullet (\overline{CS} = 0)$
$CS^* = 1$ signifies all chip enables and chip select active

Table 2.
Truth Table for
Control and Data Bus Pin Status

(CS*)	$\overline{RD}$	$\overline{WR}$	AD_{0-7} During Data Portion of Cycle	8185 Function
0	X	X	Hi-Impedance	No Function
1	0	1	Data from Memory	Read
1	1	0	Data to Memory	Write
1	1	1	Hi-Impedance	Reading, but not Driving Data Bus

NOTE:
X: Don't Care.

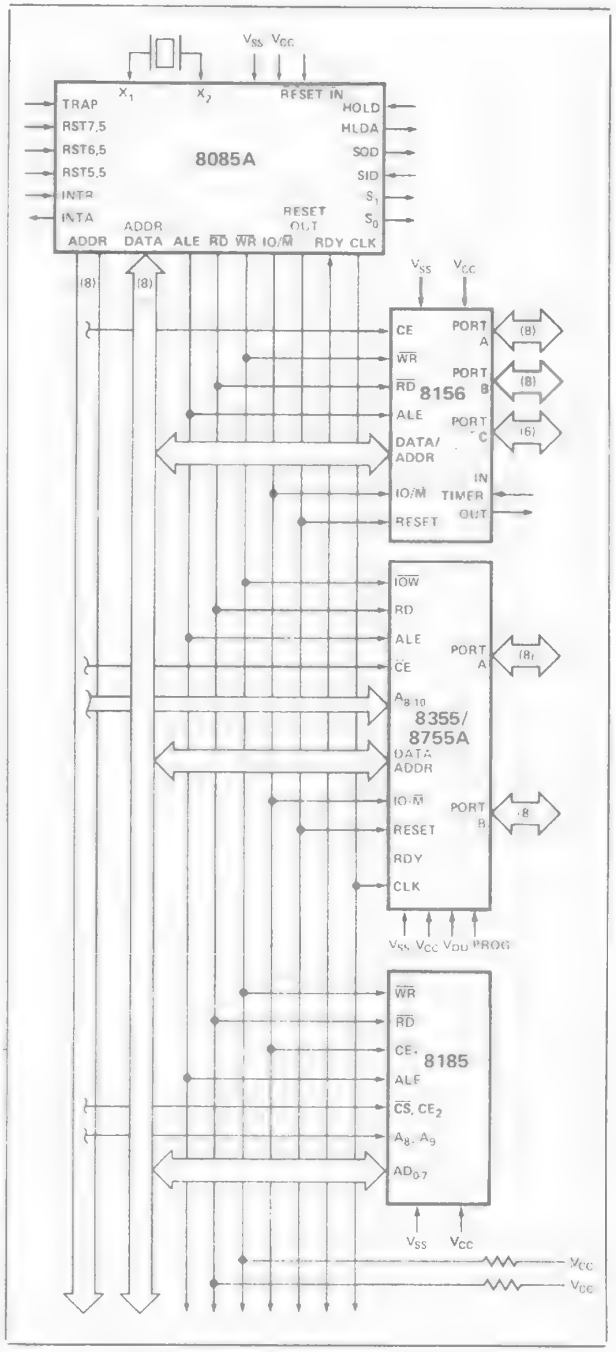


Figure 3. 8185 in an MCS-85 System

4 Chips:
2K Bytes ROM
1.25K Bytes RAM
38 I/O Lines
1 Counter/Timer
2 Serial I/O Lines
5 Interrupt Inputs

iAPX 88 FIVE CHIP SYSTEM:

- 1.25 K Bytes RAM
- 2 K Bytes ROM
- 38 I/O Pins
- 1 Internal Timer
- 2 Interrupt Levels

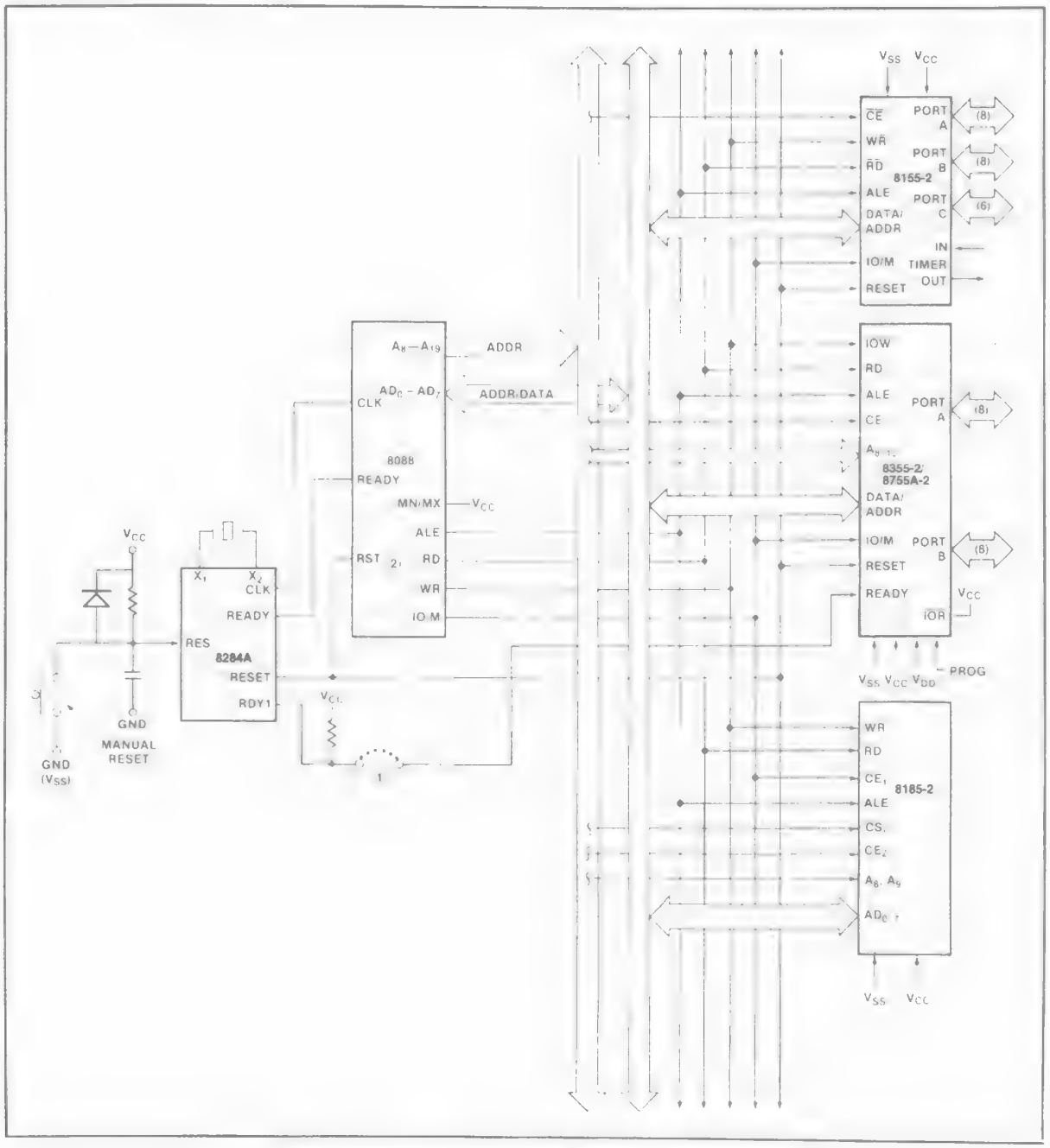


Figure 4. iAPX 88 Five Chip System Configuration

AFN-01230C

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... 0°C to +70°C
Storage Temperature ..... -65°C to +150°C
Voltage on Any Pin
with Respect to Ground ..... -0.5V to +7V
Power Dissipation 1.5W

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

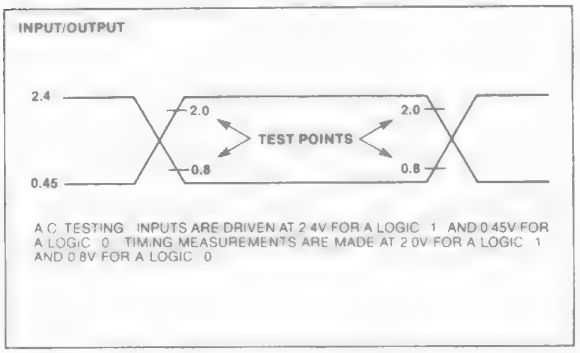
D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ± 5%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	-0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC}+0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2mA
V_{OH}	Output High Voltage	2.4			I_{OH} = − 400μA
I_{IL}	Input Leakage		±10	μA	0V ≤ V_{IN} ≤ V_{CC}
I_{LO}	Output Leakage Current		±10	μA	0.45V ≤ V_{OUT} ≤ V_{CC}
I_{CC}	V_{CC} Supply Current Powered Up		100	mA	
	Powered Down		15	mA	

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ± 5%)

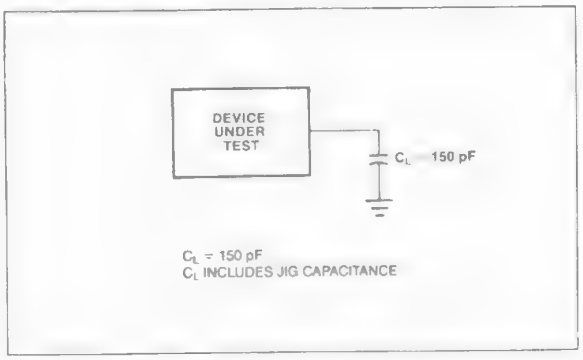
Symbol	Parameter	8185		8185-2		Units
		Min.	Max.	Min.	Max.	
t_{AL}	Address to Latch Set Up Time	50		30		ns
t_{LA}	Address Hold Time After Latch	80		30		ns
t_{LC}	Latch to READ/WRITE Control	100		40		ns
t_{RD}	Valid Data Out Delay from READ Control		170		140	ns
t_{LD}	ALE to Data Out Valid		300		200	ns
t_{LL}	Latch Enable Width	100		70		ns
t_{RDF}	Data Bus Float After READ	0	100	0	80	ns
t_{CL}	READ/WRITE Control to Latch Enable	20		10		ns
t_{CC}	READ/WRITE Control Width	250		200		ns
t_{DW}	Data In to WRITE Set Up Time	150		150		ns
t_{WD}	Data In Hold Time After WRITE	20		20		ns
t_{SC}	Chip Select Set Up to Control Line	10		10		ns
t_{CS}	Chip Select Hold Time After Control	10		10		ns
t_{ALCE}	Chip Enable Set Up to ALE Falling	30		10		ns
t_{LACE}	Chip Enable Hold Time After ALE	50		30		ns

A.C. TESTING INPUT, OUTPUT WAVEFORM



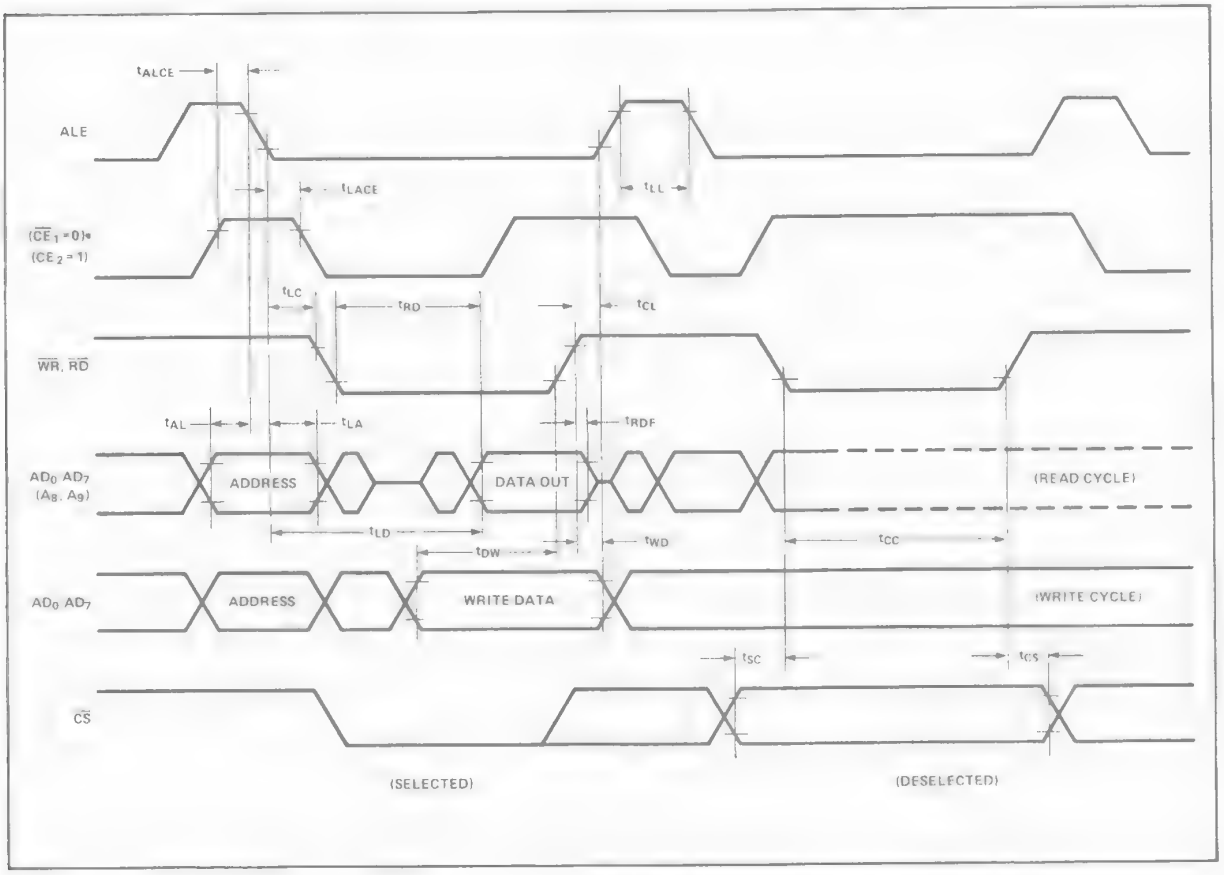
A.C. TESTING: INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0". TIMING MEASUREMENTS ARE MADE AT 2.0V FOR A LOGIC "1" AND 0.8V FOR A LOGIC "0".

A.C. TESTING LOAD CIRCUIT



C_L = 150 pF
C_L INCLUDES JIG CAPACITANCE

WAVEFORM

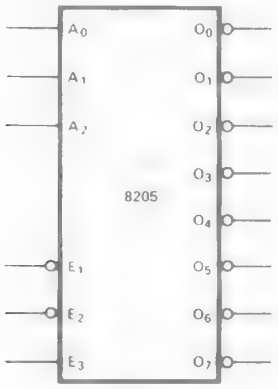


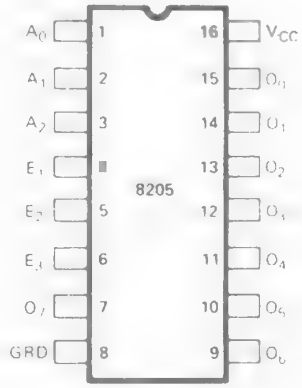
8205
HIGH SPEED 1 OUT OF 8 BINARY DECODER

- **I/O Port or Memory Selector**
- **Simple Expansion — Enable Inputs**
- **High Speed Schottky Bipolar Technology — 18ns Max. Delay**
- **Directly Compatible with TTL Logic Circuits**
- **Low Input Load Current — .25 mA max., 1/6 Standard TTL Input Load**
- **Minimum Line Reflection — Low Voltage Diode Input Clamp**
- **Outputs Sink 10 mA min.**
- **16-Pin Dual-In-Line Ceramic or Plastic Package**

The Intel® 8205 decoder can be used for expansion of systems which utilize input ports, output ports, and memory components with active low chip select input. When the 8205 is enabled, one of its 8 outputs goes "low," thus a single row of a memory system is selected. The 3-chip enable inputs on the 8205 allow easy system expansion. For very large systems, 8205 decoders can be cascaded such that each decoder can drive 8 other decoders for arbitrary memory expansions.

The 8205 is packaged in a standard 16-pin dual in-line package, and its performance is specified over the temperature range of 0°C to +75°C, ambient. The use of Schottky barrier diode clamped transistors to obtain fast switching speeds results in higher performance than equivalent devices made with a gold diffussion process.





ADDRESS			ENABLE			OUTPUTS							
A_0	A_1	A_2	E_1	E_2	E_3	O_0	O_1	O_2	O_3	O_4	O_5	O_6	O_7
L	L	L	L	L	H	L	H	H	H	H	H	H	H
H	L	L	L	L	H	H	L	H	H	H	H	H	H
L	H	L	L	L	H	H	H	L	H	H	H	H	H
H	H	L	L	L	H	H	H	H	L	H	H	H	H
L	L	H	L	L	H	H	H	H	H	L	H	H	H
H	L	H	L	L	H	H	H	H	H	H	L	H	H
L	H	H	L	L	H	H	H	H	H	H	H	L	H
H	H	H	L	L	H	H	H	H	H	H	H	H	L
X	X	X	L	L	L	H	H	H	H	H	H	H	H
X	X	X	H	L	L	H	H	H	H	H	H	H	H
X	X	X	L	H	L	H	H	H	H	H	H	H	H
X	X	X	H	H	L	H	H	H	H	H	H	H	H
X	X	X	H	L	H	H	H	H	H	H	H	H	H
X	X	X	L	H	H	H	H	H	H	H	H	H	H
X	X	X	H	H	H	H	H	H	H	H	H	H	H

A_0 A_2	ADDRESS INPUTS
E_1 E_3	ENABLE INPUTS
$\overline{O}_0$ $\overline{O}_7$	DECODED OUTPUTS

Figure 1. Logic Symbol

Figure 2. Pin Configuration

FUNCTIONAL DESCRIPTION

Decoder

The 8205 contains a one out of eight binary decoder. It accepts a three bit binary code and by gating this input, creates an exclusive output that represents the value of the input code.

For example, if a binary code of 101 was present on the A0, A1 and A2 address input lines, and the device was enabled, an active low signal would appear on the $\overline{O5}$ output line. Note that all of the other output pins are sitting at a logic high, thus the decoded output is said to be exclusive. The decoders outputs will follow the truth table shown below in the same manner for all other input variations.

Enable Gate

When using a decoder it is often necessary to gate the outputs with timing or enabling signals so that the exclusive output of the decoded value is synchronous with the overall system.

The 8205 has a built-in function for such gating. The three enable inputs ($\overline{E1}$, $\overline{E2}$, E3) are ANDed together and create a single enable signal for the decoder. The combination of both active "high" and active "low" device enable inputs provides the designer with a powerfully flexible gating function to help reduce package count in his system.

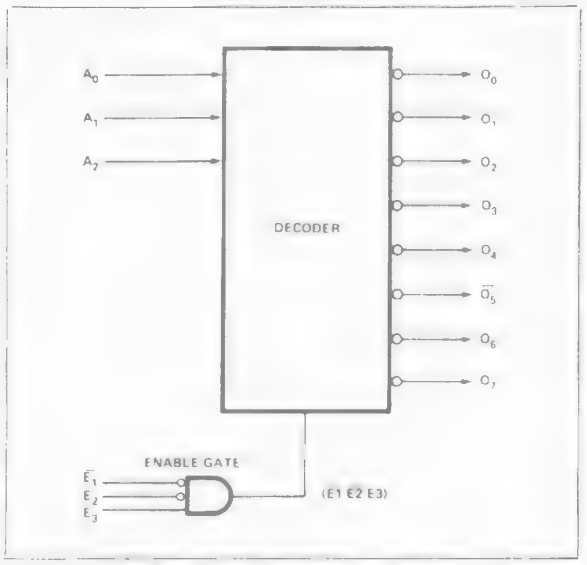


Figure 3. Enable Gate

ADDRESS			ENABLE			OUTPUTS							
A_0	A_1	A_2	E_1	E_2	E_3	0	1	2	3	4	5	6	7
L	L	L	L	L	H	L	H	H	H	H	H	H	H
H	L	L	L	L	H	H	L	H	H	H	H	H	H
L	H	L	L	L	H	H	H	L	H	H	H	H	H
H	H	L	L	L	H	H	H	H	L	H	H	H	H
L	L	H	L	L	H	H	H	H	H	L	H	H	H
H	L	H	L	L	H	H	H	H	H	H	L	H	H
L	H	H	L	L	H	H	H	H	H	H	H	L	H
H	H	H	L	L	H	H	H	H	H	H	H	H	L
X	X	X	L	L	L	H	H	H	H	H	H	H	H
X	X	X	H	L	L	H	H	H	H	H	H	H	H
X	X	X	L	H	L	H	H	H	H	H	H	H	H
X	X	X	H	H	L	H	H	H	H	H	H	H	H
X	X	X	H	L	H	H	H	H	H	H	H	H	H
X	X	X	L	H	H	H	H	H	H	H	H	H	H
X	X	X	H	H	H	H	H	H	H	H	H	H	H

Applications of the 8205

The 8205 can be used in a wide variety of applications in microcomputer systems. I/O ports can be decoded from the address bus, chip select signals can be generated to select memory devices and the type of machine state such as in 8008 systems can be derived from a simple decoding of the state lines (S0, S1, S2) of the 8008 CPU.

I/O PORT DECODER

Shown in the figure below is a typical application of the 8205. Address input lines are decoded by a group of 8205s (3). Each input has a binary weight. For example, A0 is assigned a value of 1 and is the LSB; A4 is assigned a value of 16 and is the MSB. By connecting them to the decoders as shown, an active low signal that is exclusive in nature and represents the value of the input address lines, is available at the outputs of the 8205s.

This circuit can be used to generate enable signals for I/O ports or any other decoder related application.

Note that no external gating is required to decode up to 24 exclusive devices and that a simple addition of an inverter or two will allow expansion to even larger decoder networks.

CHIP SELECT DECODER

Using a very similar circuit to the I/O port decoder, an array of 8205s can be used to create a simple interface to a 24K memory system.

The memory devices used can be either ROM or RAM and are 1K in storage capacity. 2708s and 2114As are devices typically used for this application. This type of memory device has ten (10) address inputs and an active "low" chip select ($\overline{CS}$). The lower order address bits A0–A9 which come from the microprocessor are "bussed" to all memory elements and the chip select to enable a specific device or group of devices comes from the array of 8205s. The output of the 8205 is active low so it is directly compatible with the memory components.

Basic operation is that the CPU issues an address to identify a specific memory location in which it wishes to "write" or "read" data. The most significant address bits A10-A14 are decoded by the array of 8205s and an exclusive, active low, chip select is generated that enables a specific memory device. The least significant address bits A0-A9 identify a specific location within the selected device. Thus, all addresses throughout the entire memory array are exclusive in nature and are non-redundant.

This technique can be expanded almost indefinitely to support even larger systems with the addition of a few inverters and an extra decoder (8205).

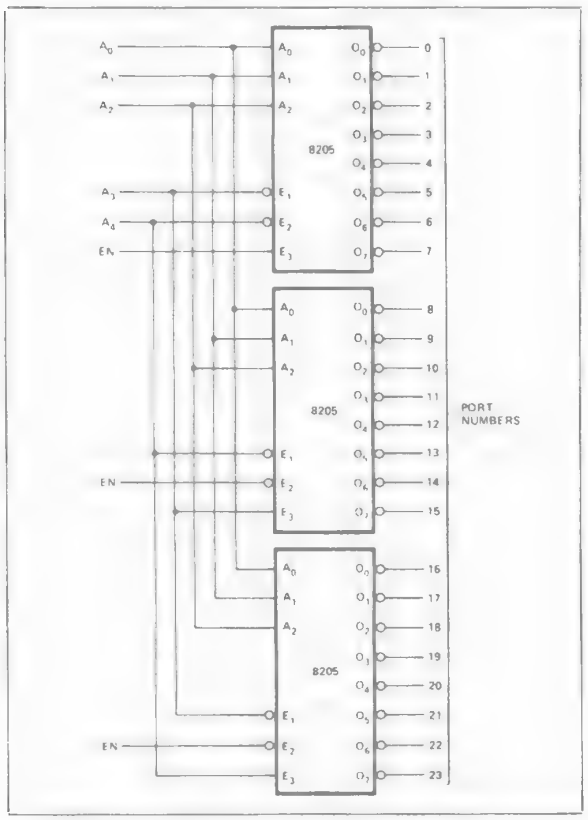


Figure 4. I/O Port Decoder

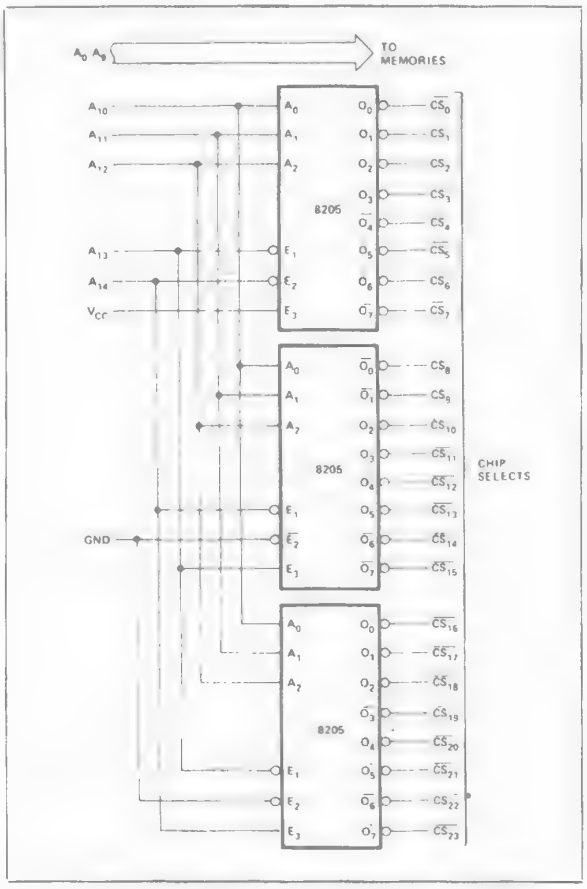


Figure 5. 24K Memory Interface

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias:
- Ceramic ..... −65°C to +125°C
- Plastic ..... −65°C to +75°C

Storage Temperature ..... −65°C to +160°C
All Output or Supply Voltages ..... −0.5 to +7 Volts
All Input Voltages ..... −1.0 to +5.5 Volts
Output Currents ..... 125 mA

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or at any other condition above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to +75°C, V_{CC} = 5V ±5%)

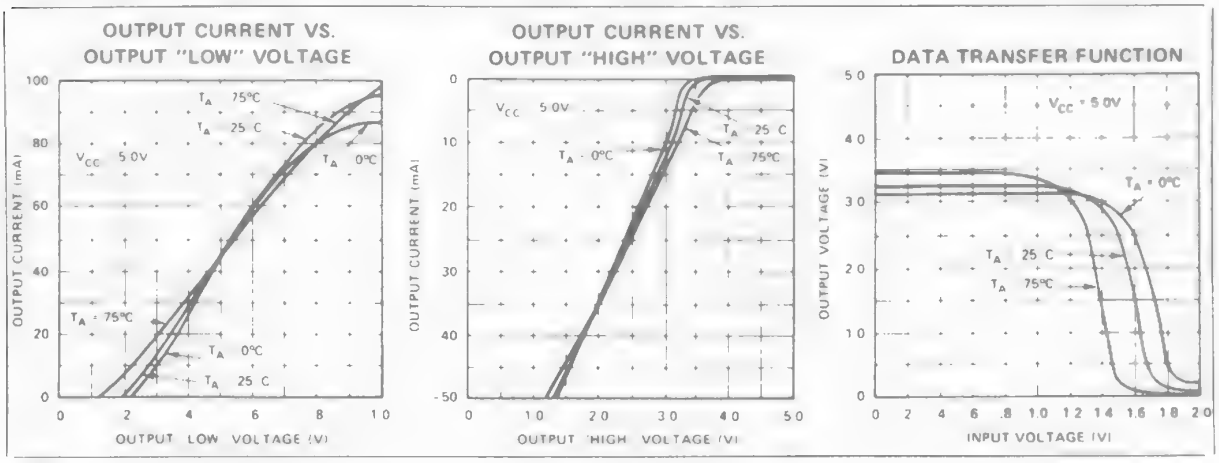
Symbol	Parameter	Limit Min.	Limit Max.	Unit	Test Conditions
I_F	INPUT LOAD CURRENT		−0.25	mA	V_{CC} = 5.25V, V_F = 0.45V
I_R	INPUT LEAKAGE CURRENT		10	μA	V_{CC} = 5.25V, V_R = 5.25V
V_C	INPUT FORWARD CLAMP VOLTAGE		−1.0	V	V_{CC} = 4.75V, I_C = −5.0 mA
V_{OL}	OUTPUT "LOW" VOLTAGE		0.45	V	V_{CC} = 4.75V, I_{OL} = 10.0 mA
V_{OH}	OUTPUT HIGH VOLTAGE	2.4		V	V_{CC} = 4.75V, I_{OH} = −1.5 mA
V_{IL}	INPUT "LOW" VOLTAGE		0.85	V	V_{CC} = 5.0V
V_{IH}	INPUT "HIGH" VOLTAGE	2.0		V	V_{CC} = 5.0V
I_{SC}	OUTPUT HIGH SHORT CIRCUIT CURRENT	−40	120	mA	V_{CC} = 5.0V, V_{OUT} = 0V
V_{OX}	OUTPUT "LOW" VOLTAGE @ HIGH CURRENT		0.8	V	V_{CC} = 5.0V, I_{OX} = 40 mA
I_{CC}	POWER SUPPLY CURRENT ●		70	mA	V_{CC} = 5.25V

A.C. CHARACTERISTICS (T_A = 0°C to +75°C, V_{CC} = 5V ±5%; unless otherwise specified)

Symbol	Parameter		Max. Limit	Unit	Test Conditions
t_{AA}	ADDRESS OR ENABLE TO OUTPUT DELAY		18	ns	
t_{CE}			18	ns	
t_{CD}			18	ns	
t_{CC}			18	ns	
C_{IN} (1)	INPUT CAPACITANCE	P8205	4(typ.)	pF	f = 1 MHz, V_{CC} = 0V
		C8205	5(typ.)	pF	V_{BIAS} = 2.0V, T_A = 25°C

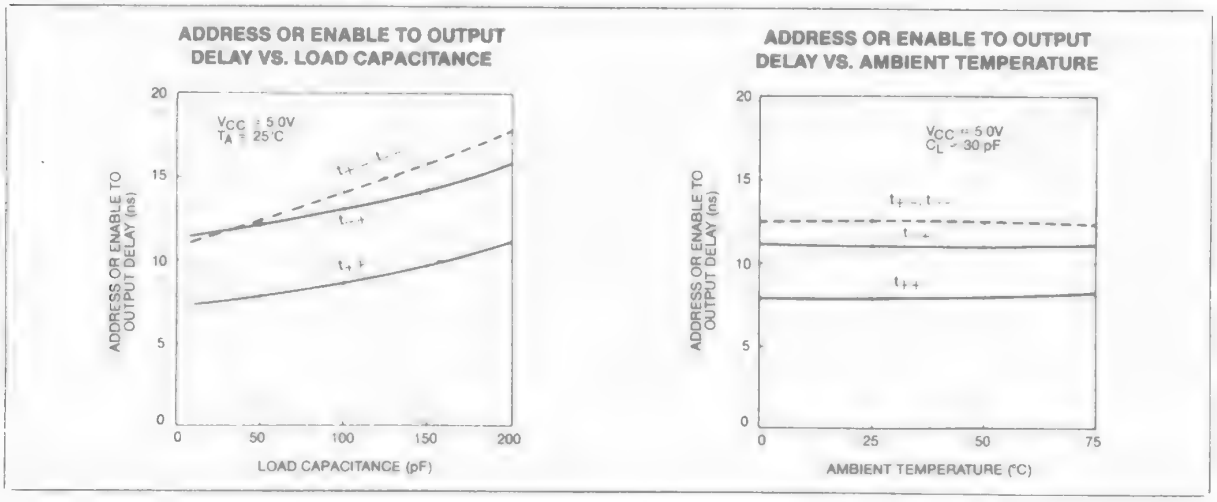
1. This parameter is periodically sampled and is not 100% tested

TYPICAL CHARACTERISTICS



AFN-00204C

TYPICAL CHARACTERISTICS (Continued)



SWITCHING CHARACTERISTICS

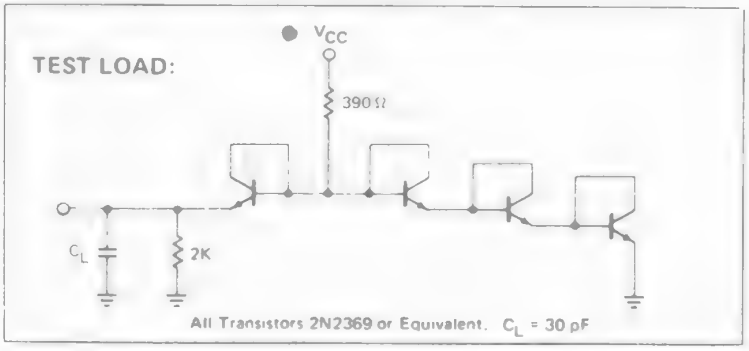
CONDITIONS OF TEST:

Input pulse amplitudes: 2.5V

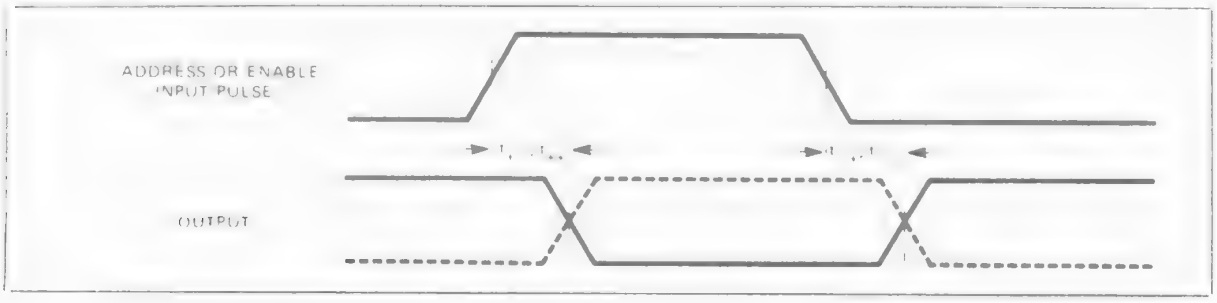
Input rise and fall times: 5 nsec between 1V and 2V

Measurements are made at 1.5V

TEST LOAD



WAVEFORMS



8212
8-BIT INPUT/OUTPUT PORT

- **Fully Parallel 8-Bit Data Register and Buffer**
- **Service Request Flip-Flop for Interrupt Generation**
- **Low Input Load Current — .25mA Max.**
- **Three State Outputs**
- **Outputs Sink 15mA**
- **3.65V Output High Voltage for Direct Interface to 8008, 8080A, or 8085A CPU**
- **Asynchronous Register Clear**
- **Replaces Buffers, Latches and Multiplexers in Microcomputer Systems**
- **Reduces System Package Count**
- **Available in EXPRESS**
  - **Standard Temperature Range**
  - **Extended Temperature Range**

The 8212 input/output port consists of an 8-bit latch with 3-state output buffers along with control and device selection logic. Also included is a service request flip-flop for the generation and control of interrupts to the microprocessor.

The device is multimode in nature. It can be used to implement latches, gated buffers or multiplexers. Thus, all of the principal peripheral and input/output functions of a microcomputer system can be implemented with this device.

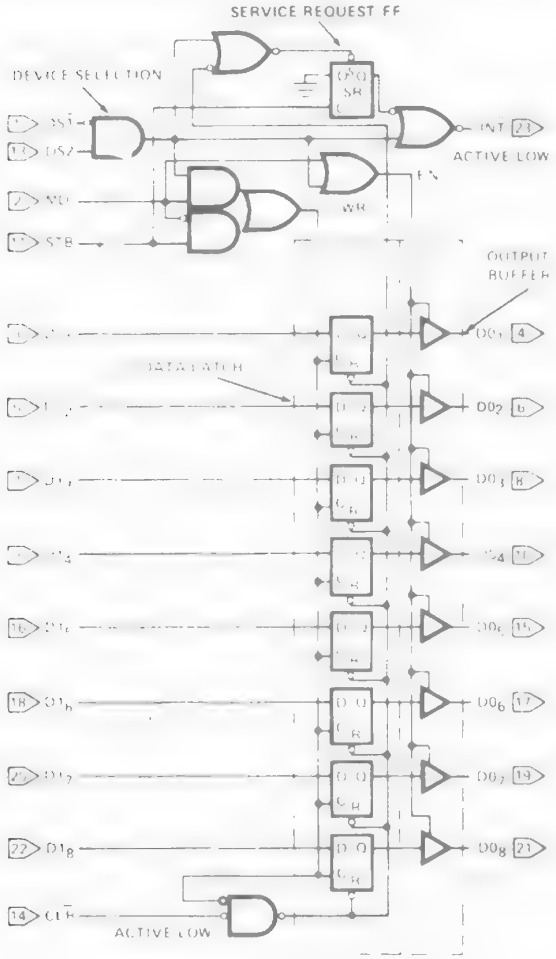
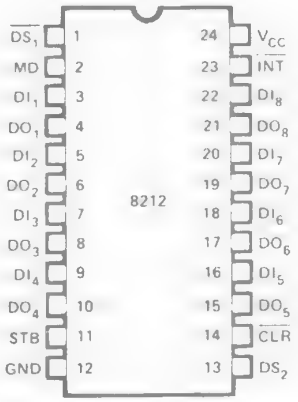


Figure 1. Logic Diagram



DI_1 DI_8	DATA IN
DO_1 DO_8	DATA OUT
$\overline{DS_1}$ DS_2	DEVICE SELECT
MD	MODE
STB	STROBE
$\overline{INT}$	INTERRUPT (ACTIVE LOW)
$\overline{CLR}$	CLEAR (ACTIVE LOW)

Figure 2. Pin Configuration

FUNCTIONAL DESCRIPTION

Data Latch

The 8 flip-flops that make up the data latch are of a "D" type design. The output (Q) of the flip-flop will follow the data input (D) while the clock input (C) is high. Latching will occur when the clock (C) returns low.

The latched data is cleared by an asynchronous reset input ($\overline{CLR}$). (Note: Clock (C) Overrides Reset ($\overline{CLR}$).)

Output Buffer

The outputs of the data latch (Q) are connected to 3-state, non-inverting output buffers. These buffers have a common control line (EN); this control line either enables the buffer to transmit the data from the outputs of the data latch (Q) or disables the buffer, forcing the output into a high impedance state. (3-state)

The high-impedance state allows the designer to connect the 8212 directly onto the microprocessor bi-directional data bus.

Control Logic

The 8212 has control inputs $\overline{DS1}$, DS2, MD and STB. These inputs are used to control device selection, data latching, output buffer state and service request flip-flop.

$\overline{DS1}$, DS2 (Device Select)

These 2 inputs are used for device selection. When $\overline{DS1}$ is low and DS2 is high ($\overline{DS1} \cdot DS2$) the device is selected. In the selected state the output buffer is enabled and the service request flip-flop (SR) is asynchronously set.

MD (Mode)

This input is used to control the state of the output buffer and to determine the source of the clock input (C) to the data latch.

When MD is high (output mode) the output buffers are enabled and the source of clock (C) to the data latch is from the device selection logic ($\overline{DS1} \cdot DS2$).

When MD is low (input mode) the output buffer state is determined by the device selection logic ($\overline{DS1} \cdot DS2$) and the source of clock (C) to the data latch is the STB (Strobe) input.

STB (Strobe)

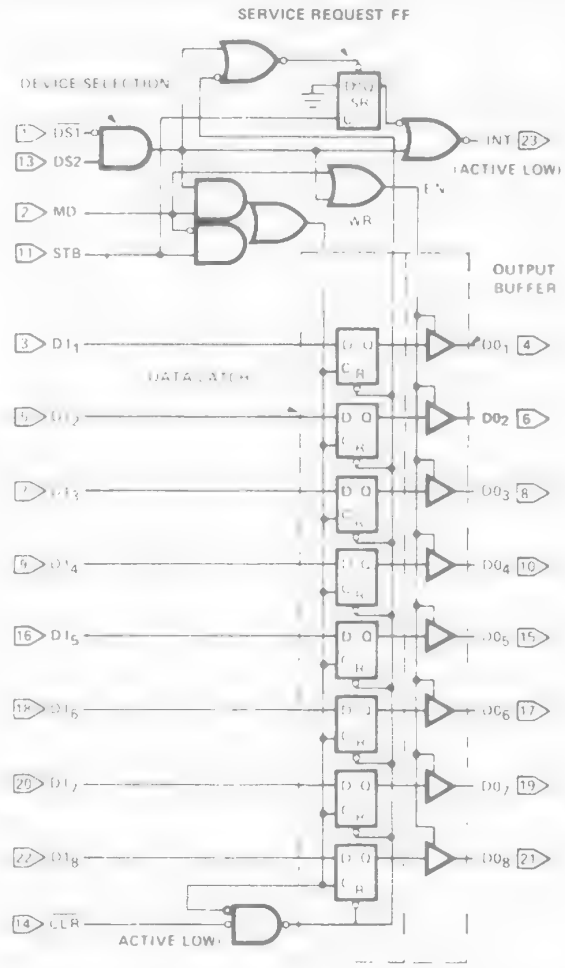
This input is used as the clock (C) to the data latch for the input mode MD = 0) and to synchronously reset the service request flip-flop (SR).

Note that the SR flip-flop is negative edge triggered.

Service Request Flip-Flop

The (SR) flip-flop is used to generate and control interrupts in microcomputer systems. It is asynchronously set by the $\overline{CLR}$ input (active low). When the (SR) flip-flop is set it is in the non-interrupting state.

The output of the (SR) flip-flop (Q) is connected to an inverting input of a "NOR" gate. The other input to the "NOR" gate is non-inverting and is connected to the device selection logic ($\overline{DS1} \cdot DS2$). The output of the "NOR" gate ($\overline{INT}$) is active low (interrupting state) for connection to active low input priority generating circuits.



STB	MD	($DS_1 \cdot DS_2$)	DATA OUT EQUALS
0	0	0	3 STATE
1	0	0	3 STATE
0	1	0	DATA LATCH
1	1	0	DATA LATCH
0	0	1	DATA LATCH
1	0	1	DATA IN
0	1	1	DATA IN
1	1	1	DATA IN

CLR	($\overline{DS_1} \cdot DS_2$)	STB	*SR	INT
0	0	0	1	1
0	1	0	1	0
1	1	↑	0	0
1	1	0	1	0
1	0	0	1	1
1	1	↑	1	0

*INTERNAL SR FLIP FLOP

$\overline{CLR}$ – RESETS DATA LATCH
SETS SR FLIP FLOP
(NO EFFECT ON OUTPUT BUFFER)

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias Plastic ..... 0°C to +70°C
Storage Temperature ..... -65°C to +160°C
All Output or Supply Voltages ..... -0.5 to +7 Volts
All Input Voltages ..... -1.0 to 5.5 Volts
Output Currents 100mA

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A=0°C to +75°C, V_{CC}= +5V ± 5%)

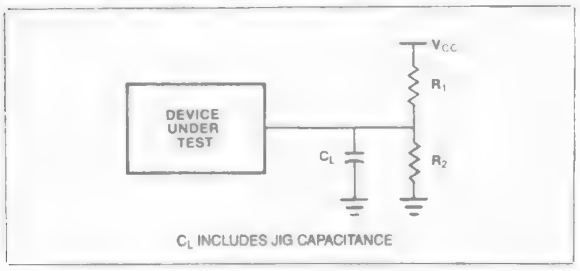
Symbol	Parameter	Limits			Unit	Test Conditions
		Min.	Typ.	Max.		
I_F	Input Load Current, ACK, DS_2, CR, DI_1-DI_8 Inputs			-.25	mA	V_F = .45V
I_F	Input Load Current MD Input			-.75	mA	V_F = .45V
I_F	Input Load Current DS_1 Input			-1.0	mA	V_F = .45V
I_R	Input Leakage Current, ACK, DS, CR, DI_1-DI_8 Inputs			10	μA	$V_R \leq V_{CC}$
I_R	Input Leakage Current MO Input			30	μA	$V_R \leq V_{CC}$
I_R	Input Leakage Current DS_1 Input			40	μA	$V_R \leq V_{CC}$
V_C	Input Forward Voltage Clamp			-1	V	I_C = -5mA
V_{IL}	Input "Low" Voltage			.85	V	
V_{IH}	Input "High" Voltage	2.0			V	
V_{OL}	Output "Low" Voltage			.45	V	I_{OL} = 15mA
V_{OH}	Output "High" Voltage	3.65	4.0		V	I_{OH} = -1mA
I_{SC}	Short Circuit Output Current	-15		-75	mA	V_O = 0V, V_{CC} = 5V
$\|I_O\|$	Output Leakage Current High Impedance State			20	μA	V_O = .45V/5.25V_{CC}
I_{CC}	Power Supply Current		90	130	mA	

CAPACITANCE* (F = 1MHz, V_{BIAS} = 2.5V, V_{CC} = +5V, T_A = 25°C)

Symbol	Test	Limits	
		Typ.	Max.
C_{IN}	DS_1 MD Input Capacitance	9pF	12pF
C_{IN}	DS_2, $\overline{CLR}$, STB, DI_1-DI_8 Input Capacitance	5pF	9pF
C_{OUT}	DO_1-DO_8 Output Capacitance	8pF	12pF

*This parameter is sampled and not 100% tested.

A.C. TESTING LOAD CIRCUIT



SWITCHING CHARACTERISTICS

Conditions of Test

Input Pulse Amplitude = 2.5V
Input Rise and Fall Times 5ns
Between 1V and 2V Measurements made at 1.5V
with 15mA and 30pF Test Load

NOTE:

1.

Test	C_L*	R_1	R_2
t_{PD}, t_{WE}, t_R, t_S, t_C	30pF	300Ω	600Ω
t_E, ENABLE↑	30pF	10KΩ	1KΩ
t_E, ENABLE↓	30pF	300Ω	600Ω
t_E, DISABLE↑	5pF	300Ω	600Ω
t_E, DISABLE↓	5pF	10KΩ	1KΩ

*Includes probe and jig capacitance.

A.C. CHARACTERISTICS (T_A = 0°C to +70°C, V_{CC} = +5V ± 5%) *

Symbol	Parameter	Limits			Unit	Test Conditions
		Min.	Typ.	Max.		
t_{PW}	Pulse Width	30			ns	
t_{PD}	Data to Output Delay			30	ns	Note 1
t_{WE}	Write Enable to Output Delay			40	ns	Note 1
t_{SET}	Data Set Up Time	15			ns	
t_H	Data Hold Time	20			ns	
t_R	Reset to Output Delay			40	ns	Note 1
t_S	Set to Output Delay			30	ns	Note 1
t_E	Output Enable/Disable Time			45	ns	Note 1
t_C	Clear to Output Delay			55	ns	Note 1

*Note: For extended Temperature EXPRESS use M8212 AC Electricals Parameters.

APPLICATIONS

Basic Schematic Symbols

Two examples of ways to draw the 8212 on system schematics—(1) the top being the detailed view showing pin numbers, and (2) the bottom being the symbolic view showing the system input or output as a system bus (bus containing 8 parallel lines). The output to the data bus is symbolic in referencing 8 parallel lines.

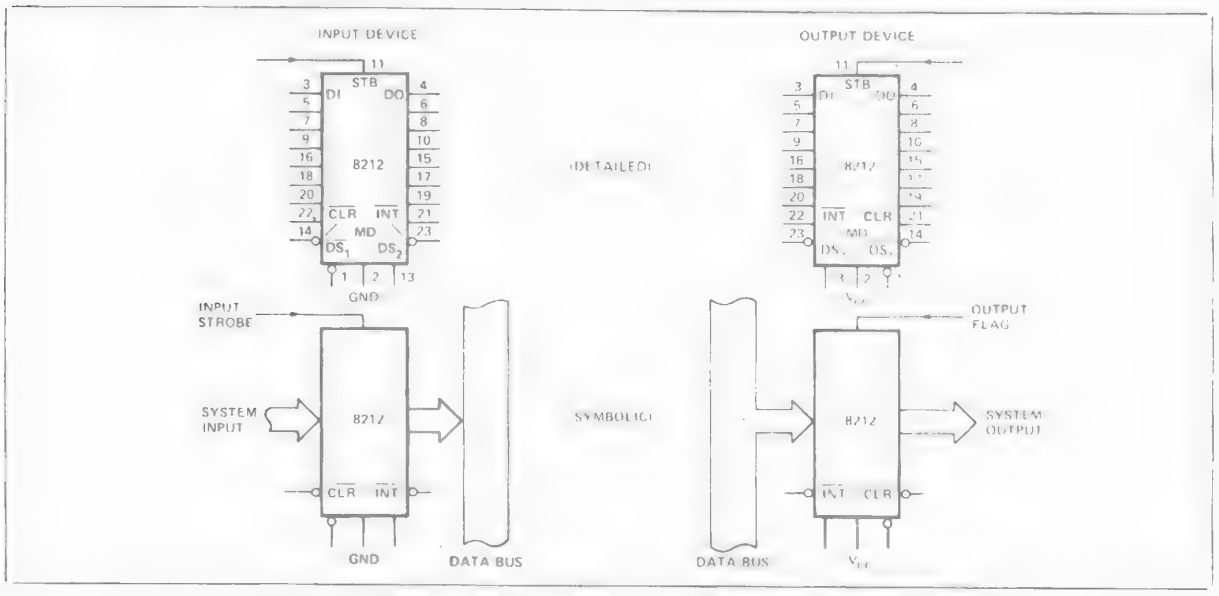


Figure 3. Basic Schematic Symbols

Gated Buffer (3-State)

The simplest use of the 8212 is that of a gated buffer. By tying the mode signal low and the strobe input high, the data latch is acting as a straight through gate. The output buffers are then enabled from the device selection logic $\overline{DS1}$ and DS2.

When the device selection logic is false, the outputs are 3-state.

When the device selection logic is true, the input data from the system is directly transferred to the output. The input data load is 250 micro amps. The output data can sink 15 milli amps. The minimum high output is 3.65 volts.

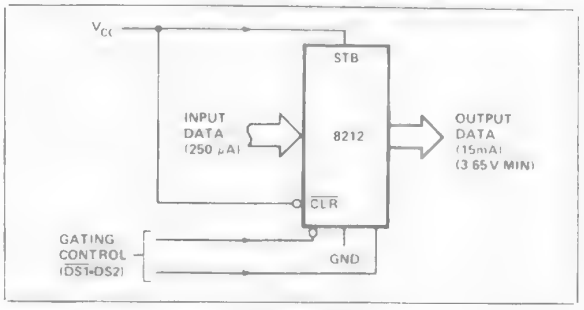


Figure 4. Gated Buffer

Bi-Directional Bus Driver

A pair of 8212's wired (back-to-back) can be used as a symmetrical drive, bi-directional bus driver. The devices are controlled by the data bus input control which is connected to $\overline{DS1}$ on the first 8212 and to DS2 on the second. One device is active, and acting as a straight through buffer the other is in 3-state mode. This is a very useful circuit in small system design.

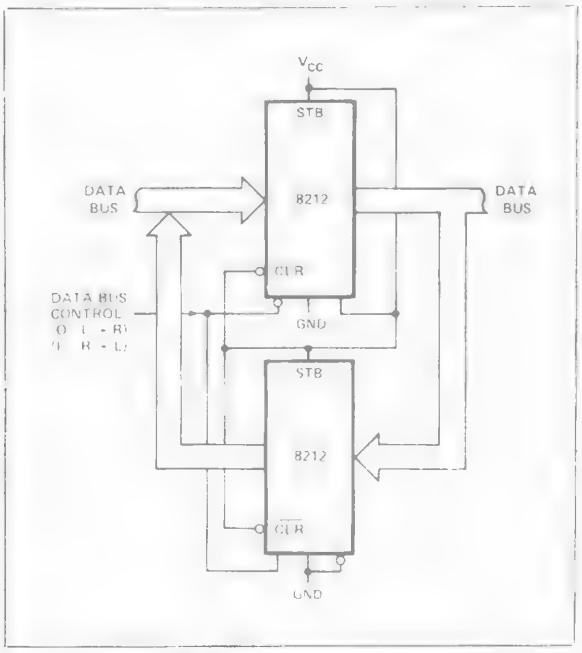


Figure 5. Bidirectional Bus Driver

Interrupting Input Port

This use of an 8212 is that of a system input port that accepts a strobe from the system input source, which in turn clears the service request flip-flop and interrupts the processor. The processor then goes through a service routine, identifies the port, and causes the device selection logic to go true — enabling the system input data onto the data bus.

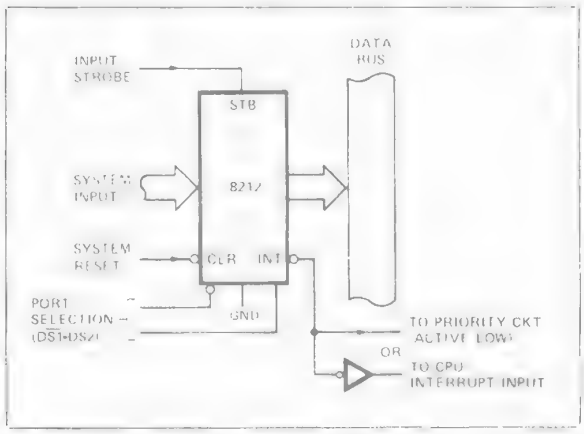


Figure 6. Interrupting Input Port

Interrupt Instruction Port

The 8212 can be used to gate the interrupt instruction, normally RESTART instructions, onto the data bus. The device is enabled from the interrupt acknowledge signal from the microprocessor and from a port selection signal This signal is normally tied to ground. ($\overline{DS1}$ could be used to multiplex a variety of interrupt instruction ports onto a common bus).

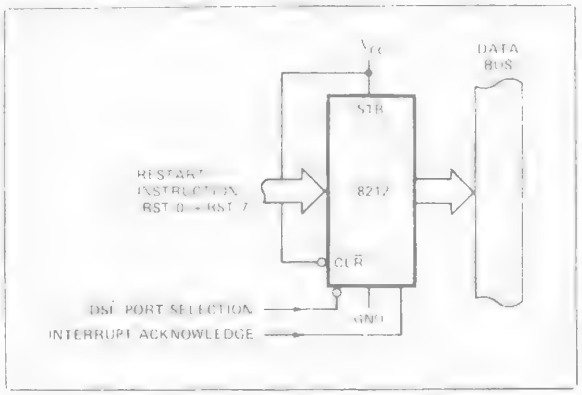


Figure 7. Interrupt Instruction Port

Output Port (With Hand-Shaking)

The 8212 can be used to transmit data from the data bus to a system output. The output strobe could be a hand-shaking signal such as "reception of data" from the device that the system is outputting to. It in turn, can interrupt the system signifying the reception of data. The selection of the port comes from the device selection logic.($\overline{DS1} \cdot DS2$)

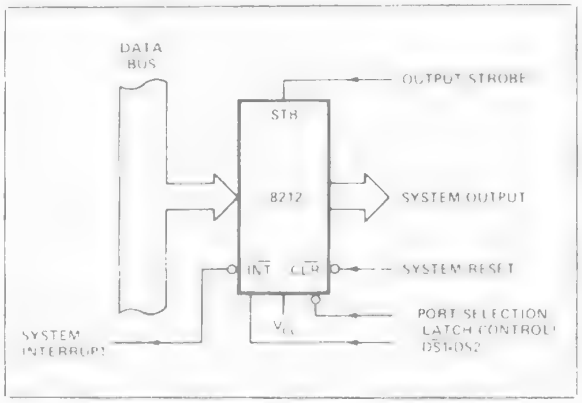
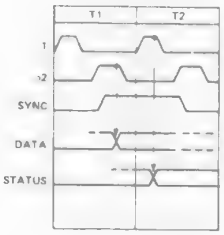
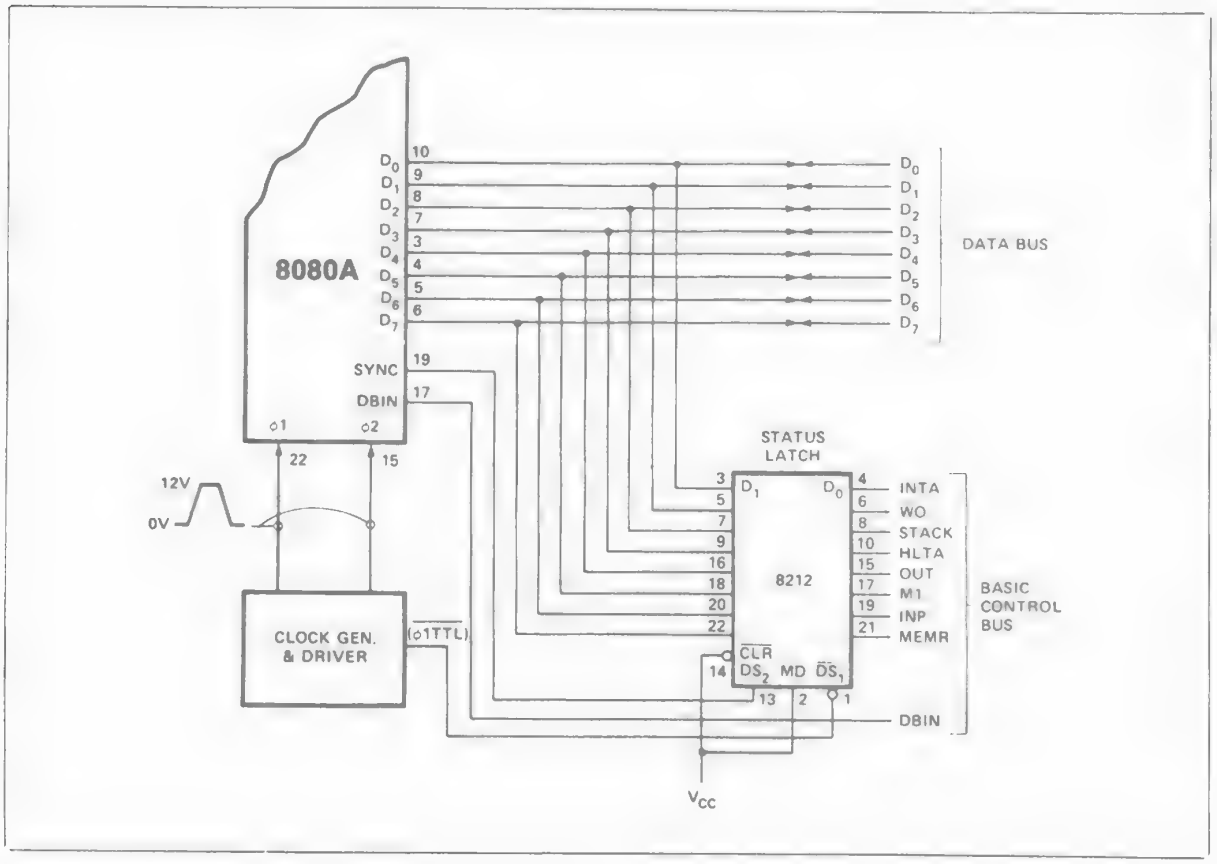


Figure 8. Output Port

808A Status Latch

Here the 8212 is used as the status latch for an 8080A microcomputer system. The input to the 8212 latch is directly from the 8080A data bus. Timing shows that when the SYNC signal is true, which is connected to the DS2 input and the phase 1 signal is true, which is a TTL level coming from the clock generator; then, the status data will be latched into the 8212.



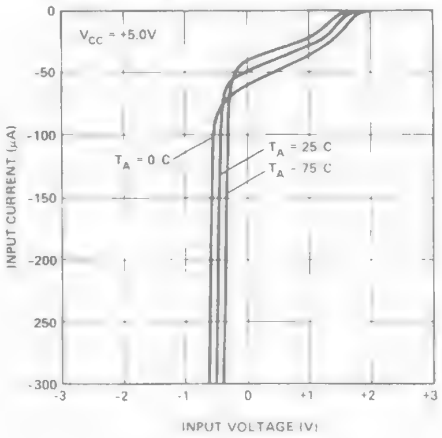


Note: The mode signal is tied high so that the output on the latch is active and enabled all the time.

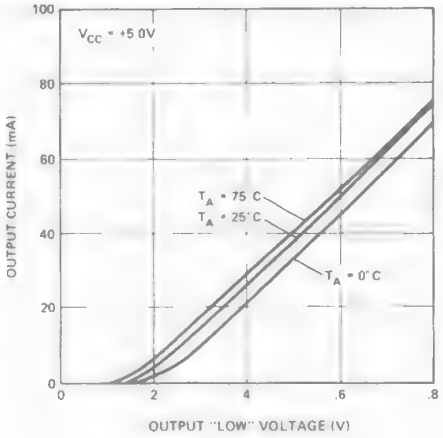
It is shown that the two areas of concern are the bi-directional data bus of the microprocessor and the control bus.

TYPICAL CHARACTERISTICS

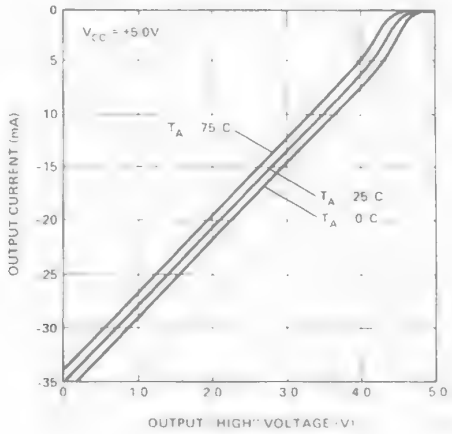
INPUT CURRENT VS. INPUT VOLTAGE



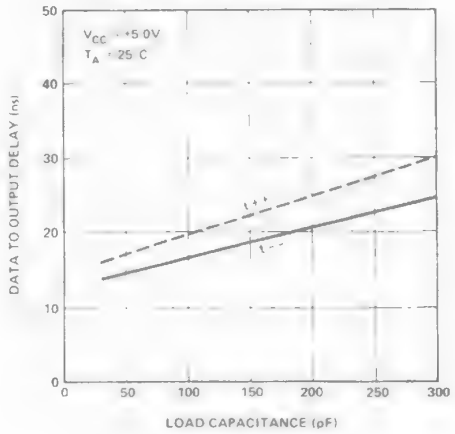
OUTPUT CURRENT VS. OUTPUT "LOW" VOLTAGE



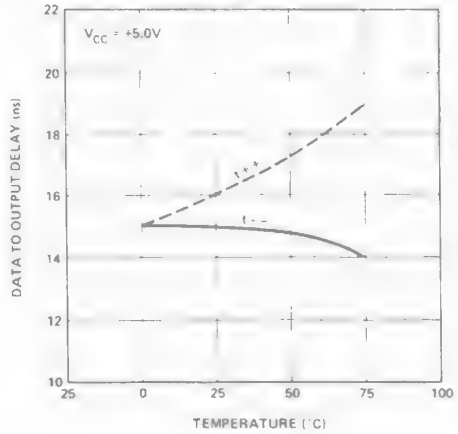
OUTPUT CURRENT VS. OUTPUT "HIGH" VOLTAGE



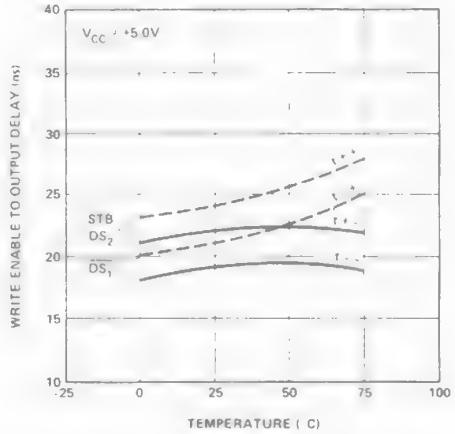
DATA TO OUTPUT DELAY VS. LOAD CAPACITANCE



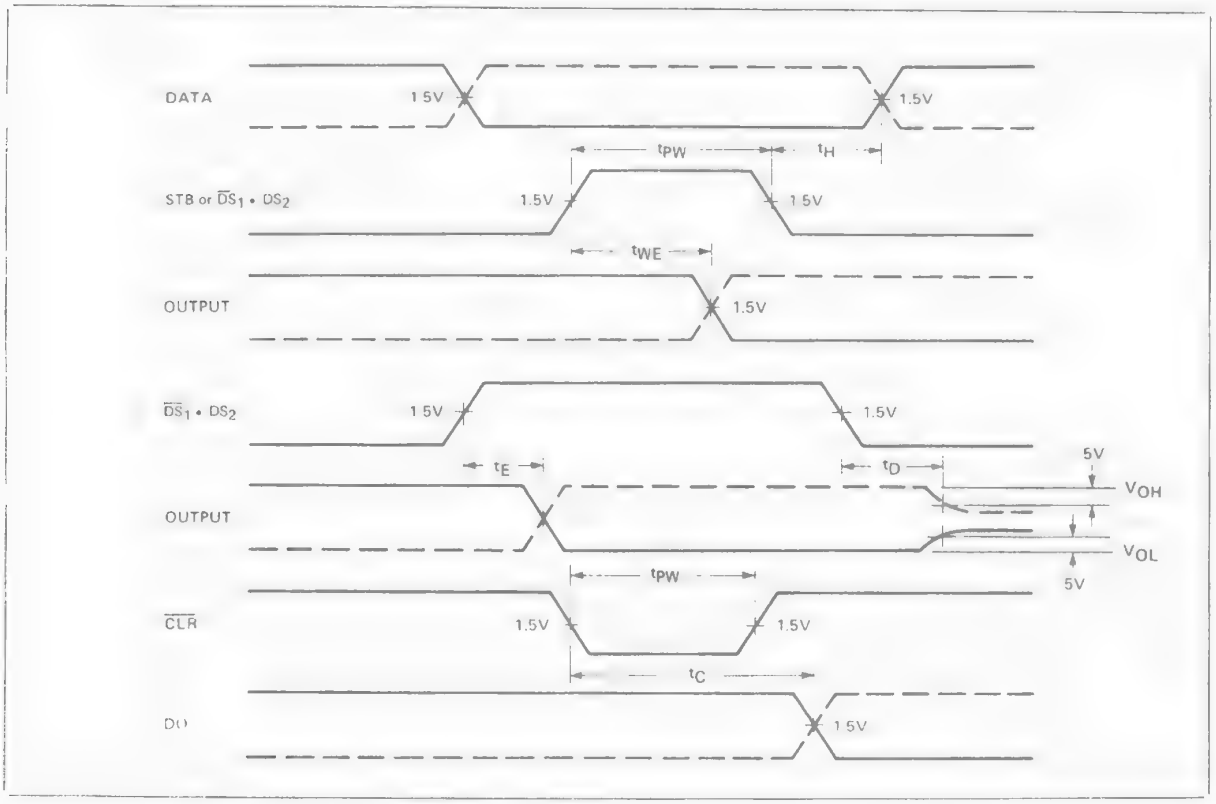
DATA TO OUTPUT DELAY VS. TEMPERATURE

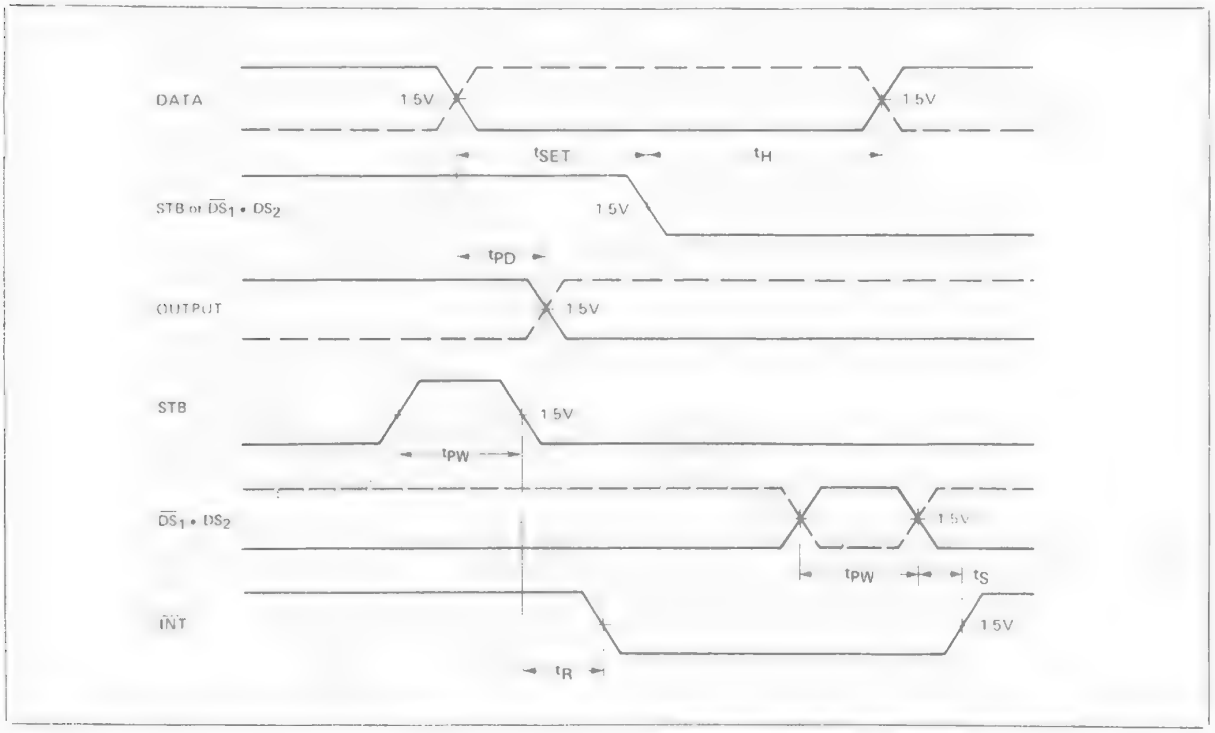


WRITE ENABLE TO OUTPUT DELAY VS. TEMPERATURE



WAVEFORMS





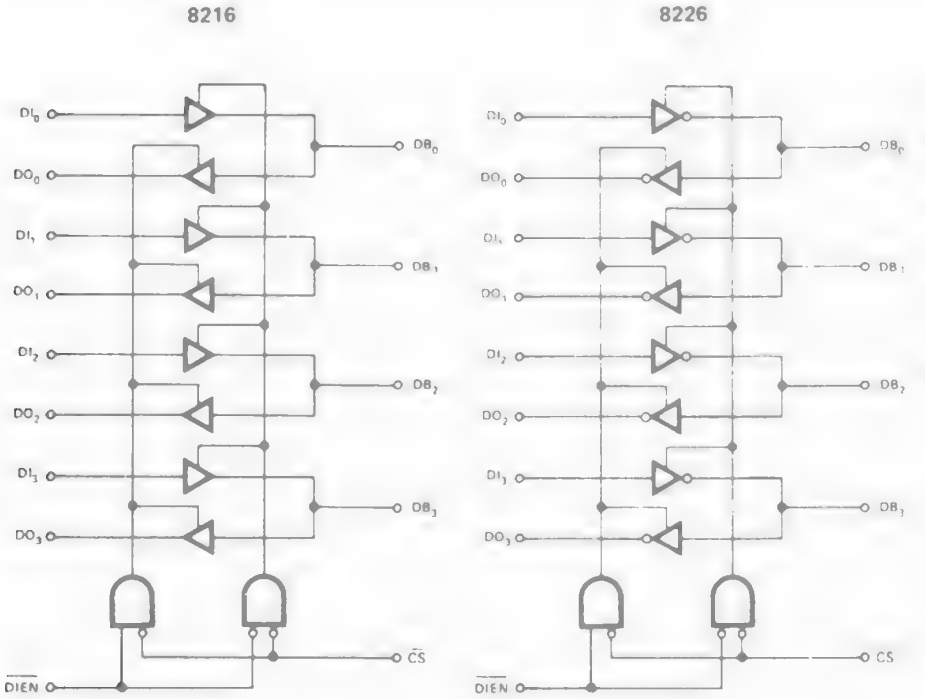
AFN-00731C

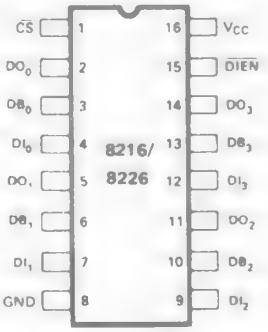
8216/8226
4-BIT PARALLEL BIDIRECTIONAL BUS DRIVER

- **Data Bus Buffer Driver for 8080 CPU**
- **Low Input Load Current — 0.25 mA Maximum**
- **High Output Drive Capability for Driving System Bus**
- **3.65V Output High Voltage for Direct Interface to 8080 CPU**
- **3-State Outputs**
- **Reduces System Package Count**
- **Available in EXPRESS**
  - **Standard Temperature Range**

The 8216/8226 is a 4-bit bidirectional bus driver/receiver. All inputs are low power TTL compatible. For driving MOS, the DO outputs provide a high 3.65V V_{OH}, and for high capacitance terminated bus structures, the DB outputs provide a high 50 mA I_{OL} capability. A non-inverting (8216) and an inverting (8226) are available to meet a wide variety of applications for buffering in microcomputer systems.

*Note: The specifications for the 3216/3226 are identical with those for the 8216/8226





DB_0 DB_3	DATA BUS BI DIRECTIONAL
DI_0 DI_3	DATA INPUT
DO_0 DO_3	DATA OUTPUT
$\overline{DIEN}$	DATA IN ENABLE DIRECTION CONTROL
$\overline{CS}$	CHIP SELECT

Figure 1. Block Diagrams

Figure 2. Pin Configuration

FUNCTIONAL DESCRIPTION

Microprocessors like the 8080 are MOS devices and are generally capable of driving a single TTL load. The same is true for MOS memory devices. While this type of drive is sufficient in small systems with few components, quite often it is necessary to buffer the microprocessor and memories when adding components or expanding to a multi-board system.

The 8216/8226 is a four bit bi-directional bus driver specifically designed to buffer microcomputer system components.

Bidirectional Driver

Each buffered line of the four bit driver consists of two separate buffers that are tri-state in nature to achieve direct bus interface and bi-directional capability. On one side of the driver the output of one buffer and the input of another are tied together (DB), this side is used to interface to the system side components such as memories, I/O, etc., because its interface is direct TTL compatible and it has high drive (50mA). On the other side of the driver the inputs and outputs are separated to provide maximum flexibility. Of course, they can be tied together so that the driver can be used to buffer a true bi-directional bus such as the 8080 Data Bus. The DO outputs on this side of the driver have a special high voltage output drive capability (3.65V) so that direct interface to the 8080 and 8008 CPUs is achieved with an adequate amount of noise immunity (350mV worst case).

Control Gating $\overline{DIEN}$, $\overline{CS}$

The $\overline{CS}$ input is actually a device select. When it is "high" the output drivers are all forced to their high-impedance state. When it is at "zero" the device is selected (enabled) and the direction of the data flow is determined by the $\overline{DIEN}$ input.

The $\overline{DIEN}$ input controls the direction of data flow (see Figure 3) for complete truth table. This direction control is accomplished by forcing one of the pair of buffers into its high impedance state and allowing the other to transmit its data. A simple two gate circuit is used for this function.

The 8216/8226 is a device that will reduce component count in microcomputer systems and at the same time enhance noise immunity to assure reliable, high performance operation.

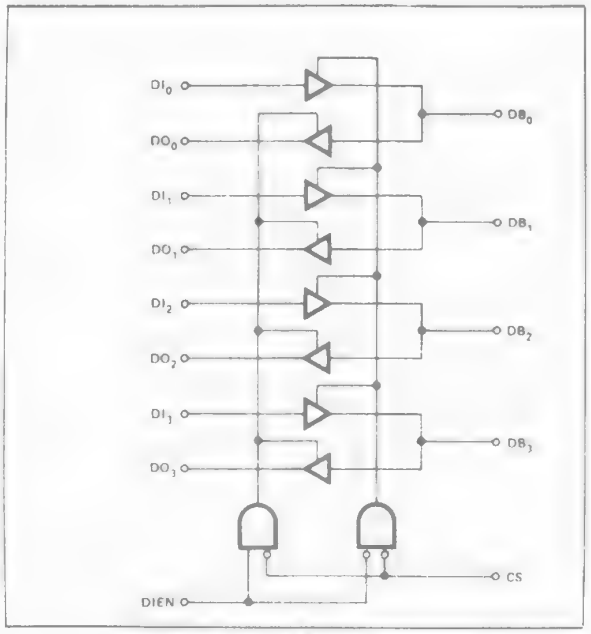
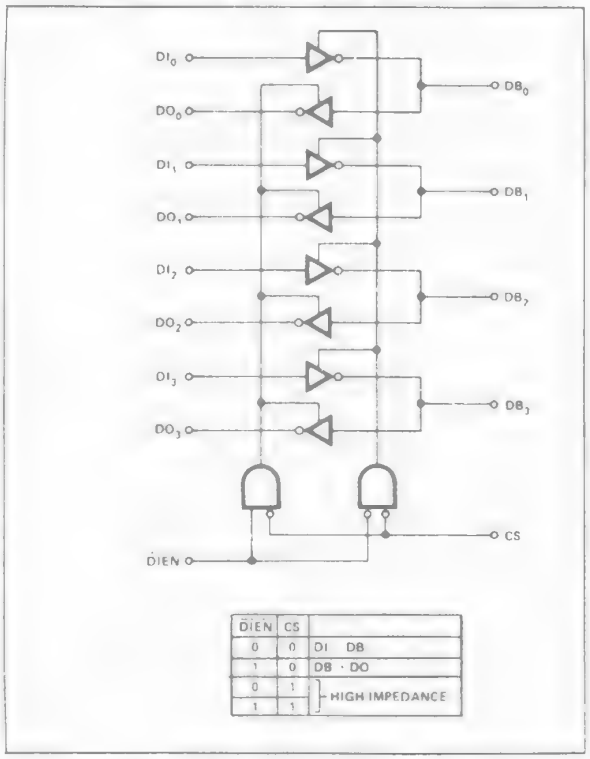


Figure 3a. 8216 Logic Diagram



DIEN	CS	
0	0	DI → DB
1	0	DB → DO
0	1	HIGH IMPEDANCE
1	1	HIGH IMPEDANCE

Figure 3b. 8226 Logic Diagram

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias . . . . . 0°C to 70°C
Storage Temperature . . . . . -65°C to +150°C
All Output and Supply Voltages . . . . . -0.5V to +7V
All Input Voltages . . . . . -1.0V to +5.5V
Output Currents . . . . . 125 mA

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to +70°C, V_{CC} = +5V ± 5%)

Symbol	Parameter		Limits Min.	Limits Typ.	Limits Max.	Unit	Conditions
I_{F1}	Input Load Current $\overline{DIEN}$, $\overline{CS}$			-0.15	-.5	mA	V_F = 0.45
I_{F2}	Input Load Current All Other Inputs			-0.08	-.25	mA	V_F = 0.45
I_{R1}	Input Leakage Current $\overline{DIEN}$, $\overline{CS}$				80	μA	V_R = 5.25V
I_{R2}	Input Leakage Current DI Inputs				40	μA	V_R = 5.25V
V_C	Input Forward Voltage Clamp				-1	V	I_C = -5mA
V_{IL}	Input "Low" Voltage				.95	V	
V_{IH}	Input "High" Voltage		2.0			V	
$\|I_O\|$	Output Leakage Current (3-State)	DO DB			20 100	μA	V_O = .45V/5.25V_{CC}
I_{CC}	Power Supply Current	8216		95	130	mA	
		8226		85	120	mA	
V_{OL1}	Output "Low" Voltage			0.3	.45	V	DO Outputs I_{OL}=15mA DB Outputs I_{OL}=25mA
V_{OL2}	Output "Low" Voltage	8216		0.5	.6	V	DB Outputs I_{OL}=55mA
		8226		0.5	.6	V	DB Outputs I_{OL}=50mA
V_{OH1}	Output "High" Voltage		3.65	4.0		V	DO Outputs I_{OH} = -1mA
V_{OH2}	Output "High" Voltage		2.4	3.0		V	DB Outputs I_{OH} = -10mA
I_{OS}	Output Short Circuit Current		-15 -30	-35 -75	-65 -120	mA mA	DO Outputs $V_O \cong$ 0V, DB Outputs V_{CC}=5.0V

NOTE:

Typical values are for T_A = 25°C, V_{CC} = 5.0V.

CAPACITANCE[5] (V_{BIAS} = 2.5V, V_{CC} = 5.0V, T_A = 25°C, f = 1 MHz)

Symbol	Parameter	Limits Min.	Typ.[1]	Max.	Unit
C_{IN}	Input Capacitance		4	8	pF
C_{OUT1}	Output Capacitance		8	10	pF
C_{OUT2}	Output Capacitance		13	18	pF

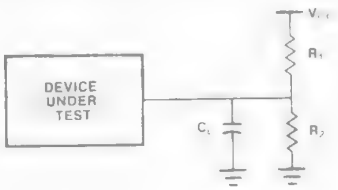
A.C. CHARACTERISTICS (T_A = 0°C to +70°C, V_{CC} = +5V ± 5%)

Symbol	Parameter		Limits Min.	Typ.[1]	Max.	Unit	Conditions
T_{PD1}	Input to Output Delay DO Outputs			15	25	ns	C_L=30pF, R_1=300Ω R_2=600Ω
T_{PD2}	Input to Output Delay DB Outputs	8216		19	30	ns	C_L=300pF, R_1=90Ω
		8226		16	25	ns	R_2 = 180Ω
T_E	Output Enable Time	8216		42	65	ns	(Note 2)
		8226		36	54	ns	(Note 3)
T_D	Output Disable Time			16	35	ns	(Note 4)

NOTE:
Input pulse amplitude of 2.5V.
Input rise and fall times of 5 ns between 1 and 2 volts.
Output loading is 5 mA and 10 pF.
Speed measurements are made at 1.5 volt levels.

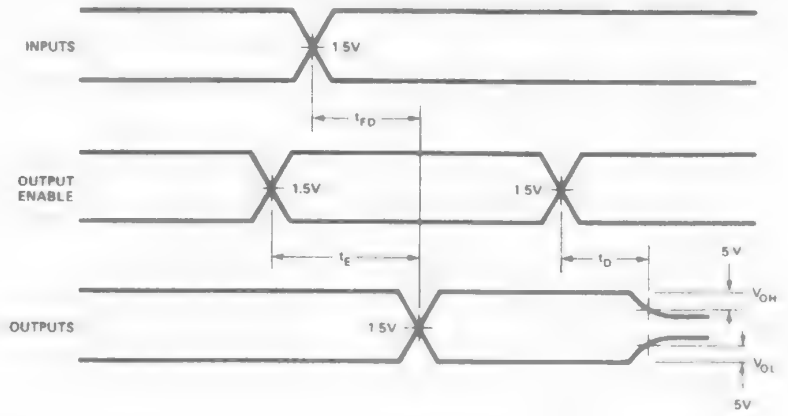
NOTES:
1. Typical values are for T_A = 25°C, V_{CC} = 5.0V.
2. DO Outputs, C_L = 30pF, R_1 = 300/10 KΩ, R_2 = 180/1KΩ; DB Outputs, C_L = 300pF, R_1 = 90/10 KΩ, R_2 = 180/1 KΩ.
3. DO Outputs, C_L = 30pF, R_1 = 300/10 KΩ, R_2 = 600/1K; DB Outputs, C_L = 300pF, R_1 = 90/10 KΩ, R_2 = 180/1 KΩ.
4. DO Outputs, C_L = 5pF, R_1 = 300/10 KΩ, R_2 = 600/1 KΩ; DB Outputs, C_L = 5pF, R_1 = 90/10 KΩ, R_2 = 180/1 KΩ.
5. This parameter is periodically sampled and not 100% tested.

A.C. TESTING LOAD CIRCUIT



AFN-00733C

WAVEFORM



AFN-00733C

PRELIMINARY

8218/8219
BIPOLAR MICROCOMPUTER BUS CONTROLLERS FOR MCS-80® AND MCS-85® FAMILIES

- **8218 for Use in MCS-80® Systems**
- **8219 for Use InMCS-85® Systems**
- **Coordinates the Sharing of a Common Bus Between Several CPU's**
- **Reduces Component Count in Multimaster Bus Arbitration Logic**
- **Single +5 Volt Power Supply**
- **28 Pin Package**

The 8218 and 8219 Microcomputer Bus Controllers consist of control logic which allows a bus master device such as a CPU or DMA channel to interface with other masters on a common bus, sharing memory and I/O devices. The 8218 and 8219 consist of:

1. Bus Arbitration Logic which operates from the Bus Clock ($\overline{BCLK}$) and resolves bus contention between devices sharing a common bus.
2. Timing Logic which when initiated by the bus arbitration logic generates timing signals for the memory and I/O command lines to guarantee set-up and hold times of the address/data lines onto the bus. The timing logic also signals to the bus arbitration logic when the current data transfer is completed and the bus is no longer needed.
3. Output Drive Logic which contains the logic and output drivers for the memory and I/O command lines.

An external RC time constant is used with the timing logic to generate the guaranteed address set-up and hold times on the bus. The 8219 can interface directly to the 8085A CPU and the 8218 interfaces to the 8080A CPU chip and the 8257 DMA controller.

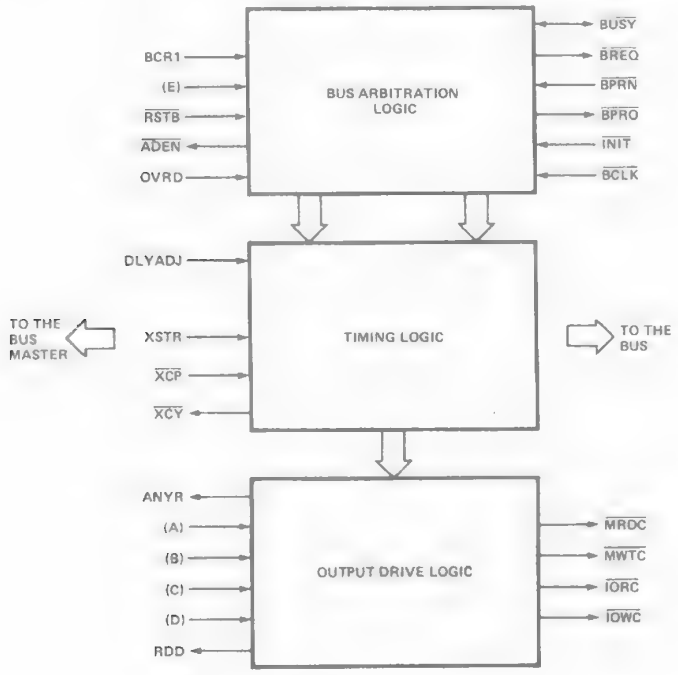
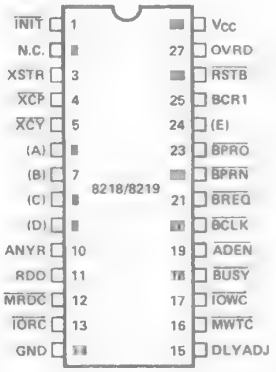


Figure 1. Block Diagram



	8218	8219
(A)	$\overline{IOWR}$	IO/$\overline{M}$
(B)	$\overline{MWTR}$	$\overline{WR}$
(C)	$\overline{IORR}$	$\overline{RD}$
(D)	$\overline{MRDR}$	$\overline{ASRQ}$
(E)	$\overline{BCR2}$	BCR2

N.C. = NO CONNECT

Figure 2. Pin Configuration

AFN-00208C

Table 1. Pin Description

Signals Interfaced Directly to the System Bus		
Symbol	**Type**	**Name and Function**
$\overline{BREQ}$	O	**Bus Request:** The Bus Request is used with a central parallel priority resolution circuit. It indicates that the device needs to access the bus for one or more data transfers. It is synchronized with the Bus Clock.
$\overline{BUSY}$	I/O	**Bus Busy:** Bus Busy indicates to all master devices on the bus that the bus is in use. It inhibits any other device from getting the bus. It is synchronized with Bus Clock.
$\overline{BCLK}$	I	**Bus Clock:** The negative edge of Bus Clock is used to synchronize the bus contention resolution circuit asynchronously to the CPU clock. It has 100ns min. period, 35%–65% duty cycle. It may be slowed, single stepped or stopped.
$\overline{BPRN}$	I	**Bus Priority In:** The Bus Priority In indicates to a device that no device of a higher priority is requesting the bus. It is synchronous with the Bus clock.
$\overline{BPRO}$	O	**Bus Priority Out:** The Bus Priority Out is used with serial priority resolution circuits. Priority may be transferred to the next lower in priority as $\overline{BPRN}$.
$\overline{INIT}$	I	**Initialize:** The Initialize resets the 8218/8219 to a known internal state.
$\overline{MRDC}$	O	**Memory Read Control:** The Memory Read Control indicates that the Master is requesting a read operation from the addressed location. It is asynchronous to the Bus Clock.
$\overline{MWTC}$	O	**Memory Write Control:** The Memory Write Control indicates that data and an address have been placed on the bus by the Master and the data is to be deposited at that location. It is asynchronous to the Bus Clock.
$\overline{IORC}$	O	**I/O Read Control:** The I/O Read Control indicates that the Master is requesting a read operation from the I/O device addressed. It is asynchronous to the Bus Clock.
$\overline{IOWC}$	O	**I/O Write Control:** The I/O Write Control indicates that Data and an I/O device address has been placed on the bus by the Master and the data is to be deposited to the I/O device. It is asynchronous to the Bus Clock.
Signals Generated or Received by the Bus Master		
BCR1/$\overline{BCR2}$	I	**Bus Control Request:** Bus Control Request 1 or Bus Control Request 2 indicate to the 8218/8219 that the Master device is making a request to control the bus. BCR2 is active low in the 8218 ($\overline{BCR2}$). BCR2 is active high in the 8219.
RSTB	I	**Request Strobe:** Request Strobe latches the status of BCR1 and BCR2 into the 8218/8219. The strobe is active low in the 8218 and negative edge triggered in the 8219.

Signals Generated or Received by the Bus Master (Continued)		
Symbol	**Type**	**Name and Function**
$\overline{ADEN}$	O	**Address and Data Enable:** Address and Data Enable indicates the Master has control of the bus. It is often used to enable Address and Data Buffers on the bus. It is synchronous with Bus Clock.
RDD	O	**Read Data:** Read Data controls the direction of the bi-directional data bus drivers. It is asynchronous to the Bus Clock. A high on RDD indicates a read mode by the master.
OVRD	I	**Override:** Override inhibits automatic deselect between transfers caused by a higher priority bus request. May be used for consecutive data transfers such as read-modify-write operations. It is asynchronous to the Bus Clock.
XSTR	I	**Transfer Start Request:** Transfer Start Request indicates to the 8218/8219 that a new data transfer cycle is requested to start. It is raised for each new word transfer in a multiple data word transfer. It is asynchronous to the Bus Clock.
$\overline{XCP}$	I	**Transfer Complete:** Transfer Complete indicates to the 8218/8219 that the data has been received by the slave device in a write cycle or transmitted by the slave and received by master in a read cycle. It is asynchronous to the Bus Clock.
$\overline{XCY}$	O	**Data Transfer:** Indicates that a data transfer is in progress. It is asynchronous to the Bus Clock.
$\overline{WR}$, $\overline{RD}$, IO/$\overline{M}$	I	**Write, Read, IO/$\overline{Memory}$:** WRITE, READ, IO/Memory are the control request inputs used by the 8085 and are internally decoded by the 8219 to produce the request signals $\overline{MRDR}$, $\overline{MWTR}$, $\overline{IORR}$, $\overline{IOWR}$. They are asynchronous to the Bus Clock. (8219 only)
$\overline{ASRQ}$	I	**Asynchronous Bus Request:** Can be used for interrupt status from the 8085. Acts like a level sensitive asynchronous bus request—no RSTB needed. It is asynchronous to the Bus Clock. (8219 only)
$\overline{MRDR}$, $\overline{MWTR}$, $\overline{IORR}$, $\overline{IOWR}$	I	**Memory Read Request, Memory Write Request, I/O Read Request, or I/O Write Request:** Indicate that address and data have been placed on the bus and the appropriate request is being made to the addressed device. Only one of these inputs should be active at any one time. They are synchronous to the Bus Clock. (8218 only)
ANYR	O	**Any Request:** Any Request is the logical OR of the active state of $\overline{MRDR}$, $\overline{MWTR}$, $\overline{IORR}$, $\overline{IOWR}$. It may be tied to XSTR when the rising edge of ANYR is used to initiate a transfer.
DLYADJ	I	**Delay Adjust:** Delay Adjust is used for connection of an external capacitor and resistor to ground to adjust the required set-up and hold time of address to control signal.

FUNCTIONAL DESCRIPTION

The 8218/8219 is a bipolar Bus Control Chip which reduces component count in the interface between a master device and the system Bus. (Master device: 8080, 8085, 8257 (DMA).)

The 8218 and 8219 serve three major functions:

1. Resolve bus contention.
2. Guarantee set-up and hold time of address/data lines to I/O and Memory read/write control signals (adjustable by external capacitor).
3. Provide sufficient drive on all bus command lines.

Bus Arbitration Logic

Bus Arbitration Logic activity begins when the Master makes a request for use of the bus on BCR1 or $\overline{BCR2}$. The request is strobed in by $\overline{RSTB}$. Following the next two falling edges of the bus clock (BCLK) the 8218/8219 outputs a bus request ($\overline{BREQ}$) and forces Bus Priority Out inactive (BPRO). See Figures 1a and 1b.

$\overline{BREQ}$ is used for requesting the bus when priority is decided by a parallel priority resolver circuit.

$\overline{BPRO}$ is used to allow lower priority devices to gain the bus when a serial priority resolving structure is used. $\overline{BPRO}$ would go to $\overline{BPRN}$ of the next lower priority Master.

When priority is granted to the Master (a low on $\overline{BPRN}$ and a high on $\overline{BUSY}$) the Master outputs a $\overline{BUSY}$ signal on the next falling edge of $\overline{BCLK}$. The $\overline{BUSY}$ signal locks the master onto the bus and prohibits the enable of any other masters onto the bus.

At the same time $\overline{BUSY}$ goes active, Address and Data Enable ($\overline{ADEN}$) goes active signifying that the Master has control of the bus. $\overline{ADEN}$ is often used to enable the bus drivers.

The Bus will be released only if the master loses priority; is not in the middle of a transfer, and Override is not active or, if the Master stops requesting the bus, is not in the middle of a data transfer, and Override is not active. $\overline{ADEN}$ then goes inactive.

Provision has been made in the 8218 to allow bus-synchronous requests. This mode is activated when BCR1, $\overline{BCR2}$ and $\overline{RSTB}$ are all low. This action asynchronously sets the synchronization flip flop (FF2) in Figure 3a.

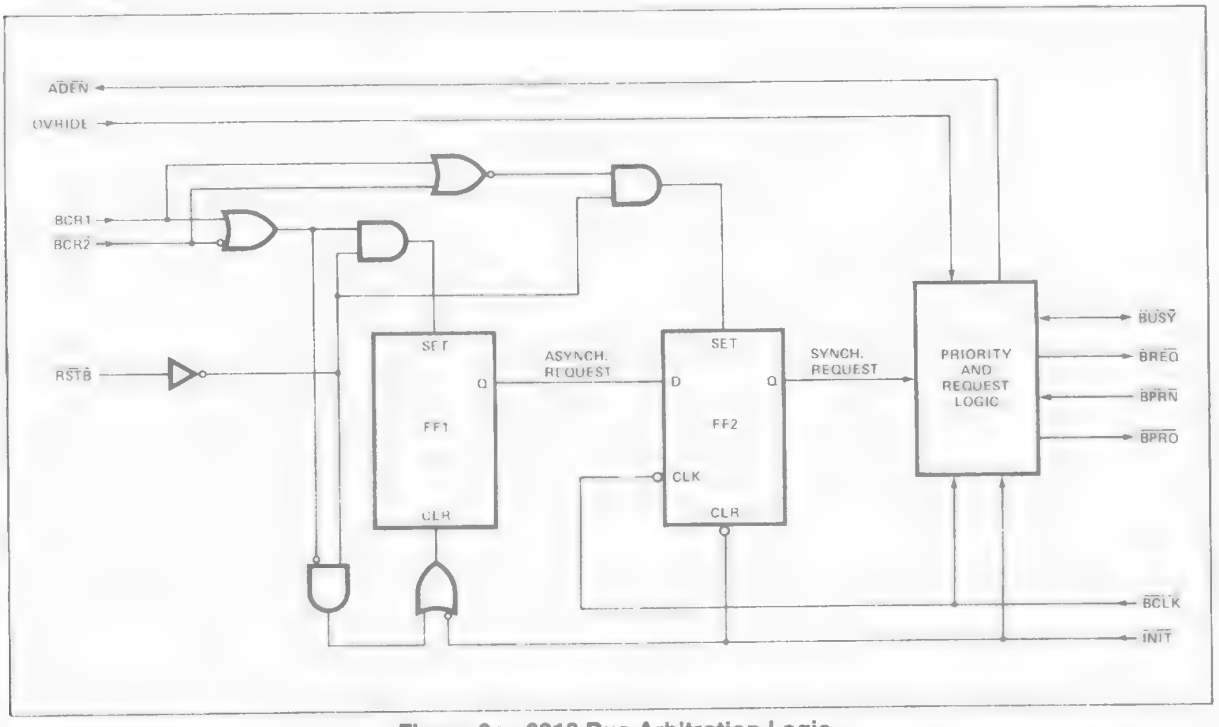


Figure 3a. 8218 Bus Arbitration Logic

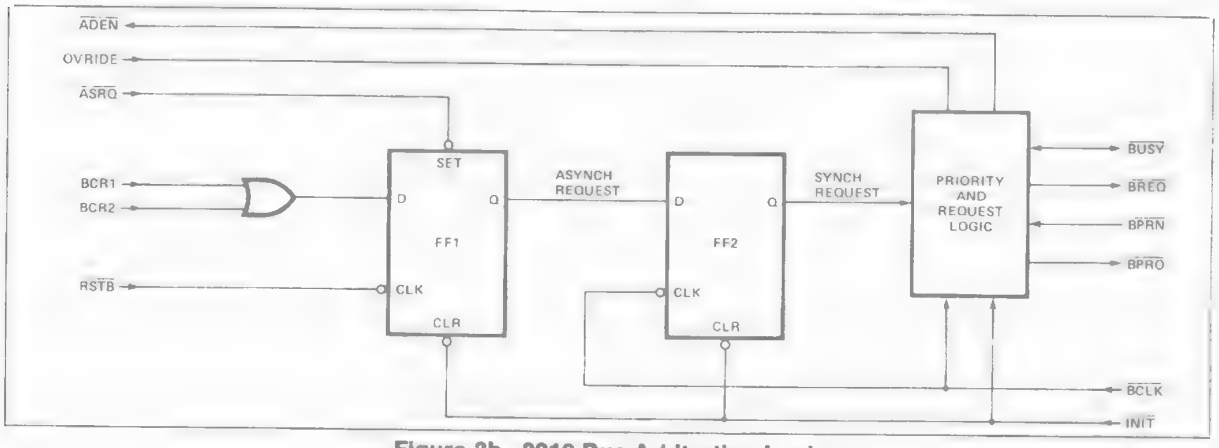


Figure 3b. 8219 Bus Arbitration Logic

Timing Logic

Timing Logic activity begins with the rising edge of XSTR (Transfer Start Request) or with $\overline{\text{ADEN}}$ going active, whichever occurs second. This action causes $\overline{\text{XCY}}$ (Transfer Cycle) to go active. 50-200ns later (depending on resistance and capacitance at DLYADJ) the appropriate Control Outputs will go active if the control input is active.

XSTR can be raised after the command goes active in the current transfer cycle so that a new transfer can be initiated immediately after the current transfer is complete.

A negative going edge on $\overline{\text{XCP}}$ (Transfer Complete) will cause the Control Outputs ($\overline{\text{MRDC}}$, etc.) to go inactive. 50-200ns later (depending on capacitance at DLYADJ) $\overline{\text{XCY}}$ will go inactive indicating the transfer cycle is completed.

Additional logic within the 8218/8219 guarantees that if a transfer cycle is started ($\overline{\text{XCY}}$ is active), but the bus is not requested ($\overline{\text{BREQ}}$ is inactive) and there is no command request input (ANYR is output low), then the transfer cycle will be cleared. This allows the bus to be released in applications where advanced bus requests are generated but the processor enters a HALT mode.

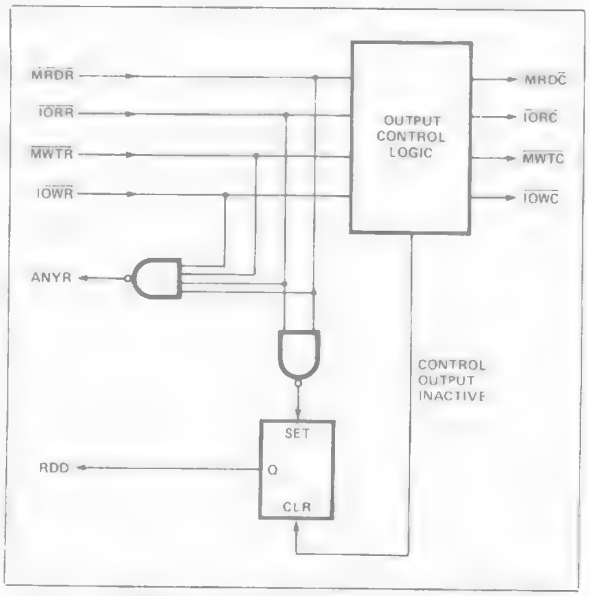


Figure 4a. 8218 Control Logic

Control Logic

The control outputs are generated in the 8219 by decoding the 8085 system control outputs (i.e., RD, WR, IO/M) or in the 8218 by directly buffering the control inputs to the control outputs for use in an 8080 or DMA system (see Figures **4a** and **4b**). The control outputs may be held high (inactive) by the Timing Logic. Also the control outputs are enabled when the Master gains control of the bus and disabled when control is relinquished.

The Control Logic also has two other outputs, ANYR (Any Request) and RDD (Read Data). ANYR goes high (active) if any control requests (IOWR, etc.) are active. RDD controls the direction of the Masters Bi-directional Data Bus Drivers. The Bus Driver will always be in the Write mode (RDD = Low) except from the start of a Read Control Request to 25 to 70ns after $\overline{\text{XCP}}$ is activated.

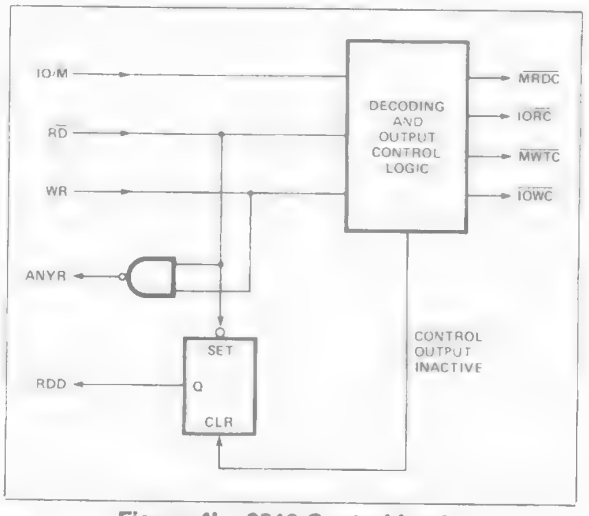


Figure 4b. 8219 Control Logic

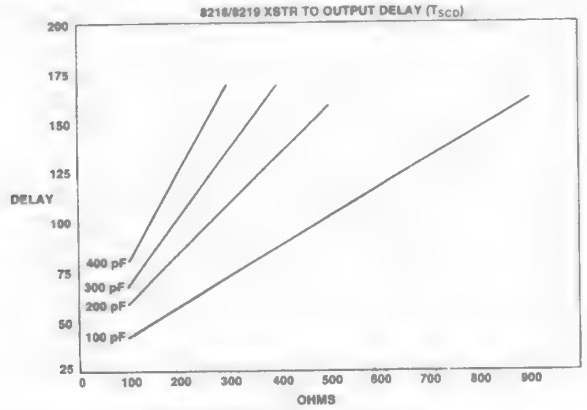
ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... -65°C to +150°C
Supply Voltage (V_{CC}) ..... -0.5V to +7V
Input Voltage ..... -1.0V to V_{CC} + 0.25V
Output Current 100mA

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C; V_{CC} = 5V ± 5%)

Symbol	Parameter	Limits Min.	Limits Typ.	Limits Max.	Unit	Test Conditions
V_C	Input Clamp Voltage			-1.0	V	V_{CC} = 0.0V, I_C = −5 mA
I_F	Input Load Current $\overline{MRDR}$/$\overline{INTA}$/$\overline{MWTR}$/$\overline{WR}$ $\overline{IORR}$/$\overline{RD}$, IOWR/IO/$\overline{M}$			-0.5	mA	V_{CC} = 5.25V V_F = 0.45V
	Other			-0.5	mA	
I_R	Input Leakage Current			100	μA	V_{CC} = 5.25 V_R = 5.25
V_{TH}	Input Threshold Voltage	0.8		2.0	V	V_{CC} = 5V
I_{CC}	Power Supply Current		200	240	mA	V_{CC} = 5.25V
V_{OL}	Output Low Voltage					V_{CC} = 4.75
	$\overline{MRDC}$, $\overline{MWTC}$, $\overline{IORC}$, $\overline{IOWC}$			0.45	V	I_{OL} = 32mA
	$\overline{BREQ}$, $\overline{BUSY}$			0.45	V	I_{OL} = 20mA
	$\overline{XCY}$, $\overline{RDD}$, $\overline{ADEN}$			0.45	V	I_{OL} = 16mA
	$\overline{BPRO}$, ANYR			0.45	V	I_{OL} = 3.2mA
V_{OH}	Output High Voltage					V_{CC} = 4.75V
	$\overline{MRDC}$, $\overline{MWTC}$, $\overline{IORC}$, $\overline{IOWC}$	2.4				I_{OH} = -2mA
	All Other Outputs	2.4				I_{OH} = -400μA
I_{OS}	Short Circuit Output Current	-10		-90	mA	V_{CC} = 5.25V, V_O = 0V
$I_{O\ (OFF)}$	Tri-State Output Current			-100	μA	V_{CC} = 5.25V, V_O = 0.45V
				+100	μA	V_{CC} = 5.25V, V_O = 5.25V
C_{IN}	Input Capacitance Except Busy		10	20	pF	
C_{IO}	Input Capacitance Busy		25	35	pF	

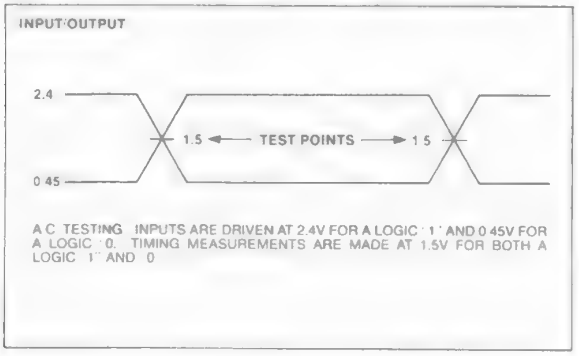


One Shot Delay Versus Delay Adjust Capacitance And Resistance

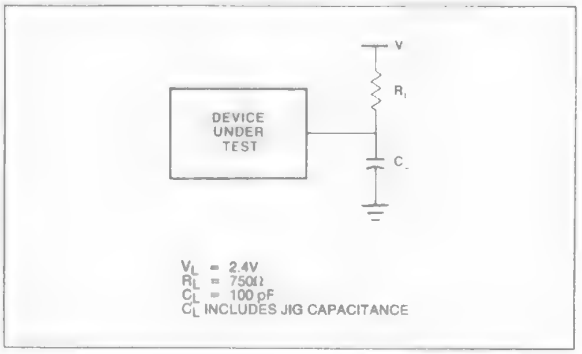
A.C. CHARACTERISTICS (T_A = 0°C to 70°C; V_{CC} = 5V ± 5%)

Symbol	Parameter	Limits Min.	Limits Typ.	Limits Max.	Unit	Test Conditions
t_{BCY}	Bus Clock Cycle Time	100			ns	35% to 65% Duty Cycle
t_{PW}	Bus Clock Pulse Width	35		0.65 t_{BCY}	ns	
t_{RQS}	$\overline{RSTB}$ to $\overline{BCLK}$ Set-Up Time	25			ns	
t_{CSS}	BCR_1 and $\overline{BCR_2}$ to $\overline{RSTB}$ Set-Up Time	15			ns	
t_{CSH}	BCR_1 and $\overline{BCR_2}$ to $\overline{RSTB}$ Hold Time	15			ns	
t_{RQD}	$\overline{BCLK}$ to $\overline{BREQ}$ Delay			35	ns	
t_{PRNS}	$\overline{BPRN}$ to $\overline{BCLK}$ Set-Up Time	23			ns	
t_{BNO}	$\overline{BRPN}$ to $\overline{BPRO}$ Delay			30	ns	
t_{BYD}	$\overline{BCLK}$ to $\overline{BUSY}$ Delay			55	ns	
t_{CAD}	$\overline{MRDR}$, $\overline{MWTR}$, $\overline{IORR}$, $\overline{IOWR}$ to ANYR Delay			30	ns	
t_{SXD}	XSTR to $\overline{XCY}$ Delay			40	ns	
t_{SCD}	XSTR to $\overline{MRDC}$, $\overline{MWTC}$, $\overline{IORC}$, $\overline{IOWC}$ Delay	50		200	ns	Adjustable by External R/C
t_{XSW}	XSTR Pulse Width	30			ns	
t_{XCD}	$\overline{XCP}$ to $\overline{MRDC}$, $\overline{MWTC}$, $\overline{IORC}$, $\overline{IOWC}$ Delay			50	ns	
t_{XCW}	$\overline{XCP}$ Pulse Width	35			ns	
t_{CCD}	$\overline{XCP}$ to $\overline{XCY}$ Delay	50		200	ns	Adjustable by External R/C
t_{CMD}	$\overline{MRDR}$, $\overline{MWTR}$, $\overline{IORR}$, $\overline{IOWR}$ to $\overline{MRDC}$, $\overline{MWTC}$, $\overline{IORC}$, $\overline{IOWC}$			35	ns	
t_{CRD}	$\overline{MRDR}$, $\overline{MWTR}$, $\overline{IORR}$, $\overline{IOWR}$ to RDD Delay			25	ns	
t_{RW}	$\overline{RSTB}$ Min. Neg. Pulse Width	30			ns	
t_{CPD}	$\overline{BCLK}$ to $\overline{BPRO}$ Delay			40	ns	
t_{XRD}	$\overline{XCP}$ to $\overline{RDD}$ Delay	25		70	ns	

A.C. TESTING INPUT, OUTPUT WAVEFORM

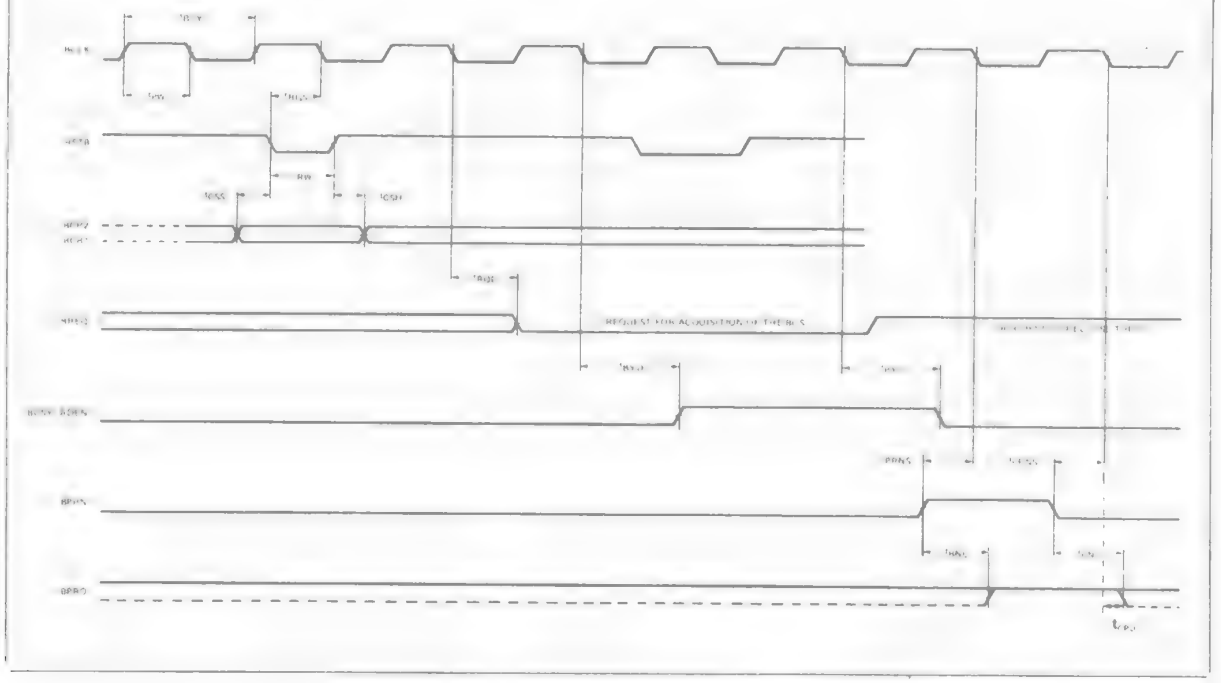


A.C. TESTING LOAD CIRCUIT

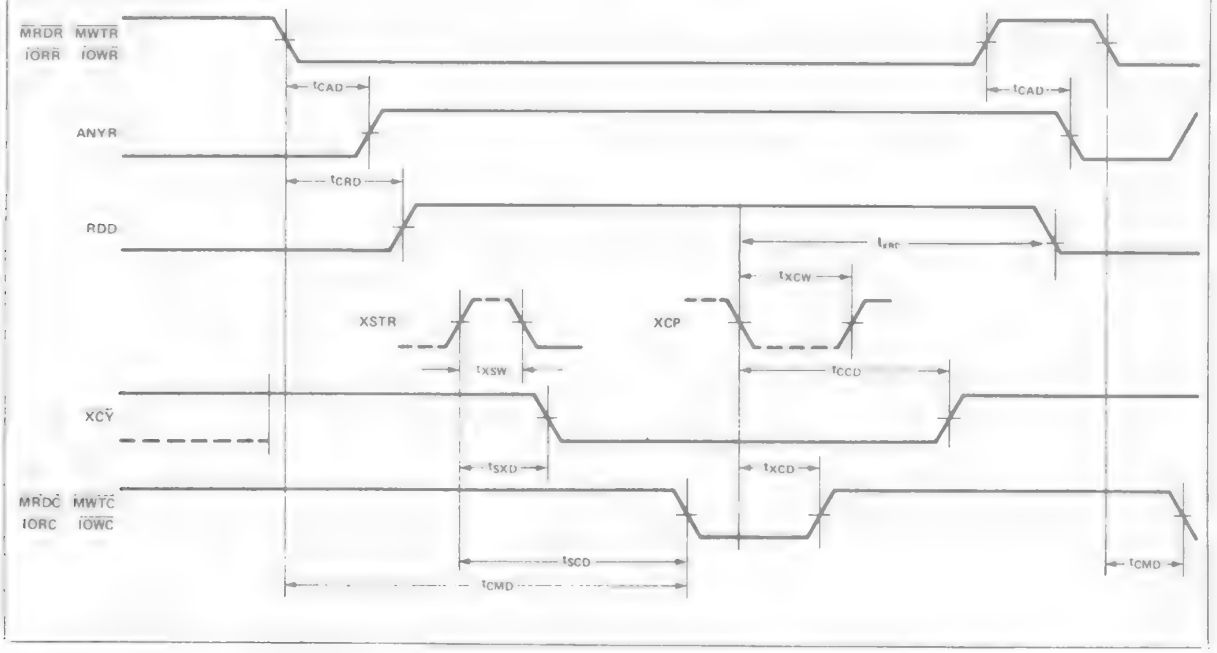


WAVEFORMS

SYNCHRONOUS BUS TIMING (System Bus Previously Not In Use)

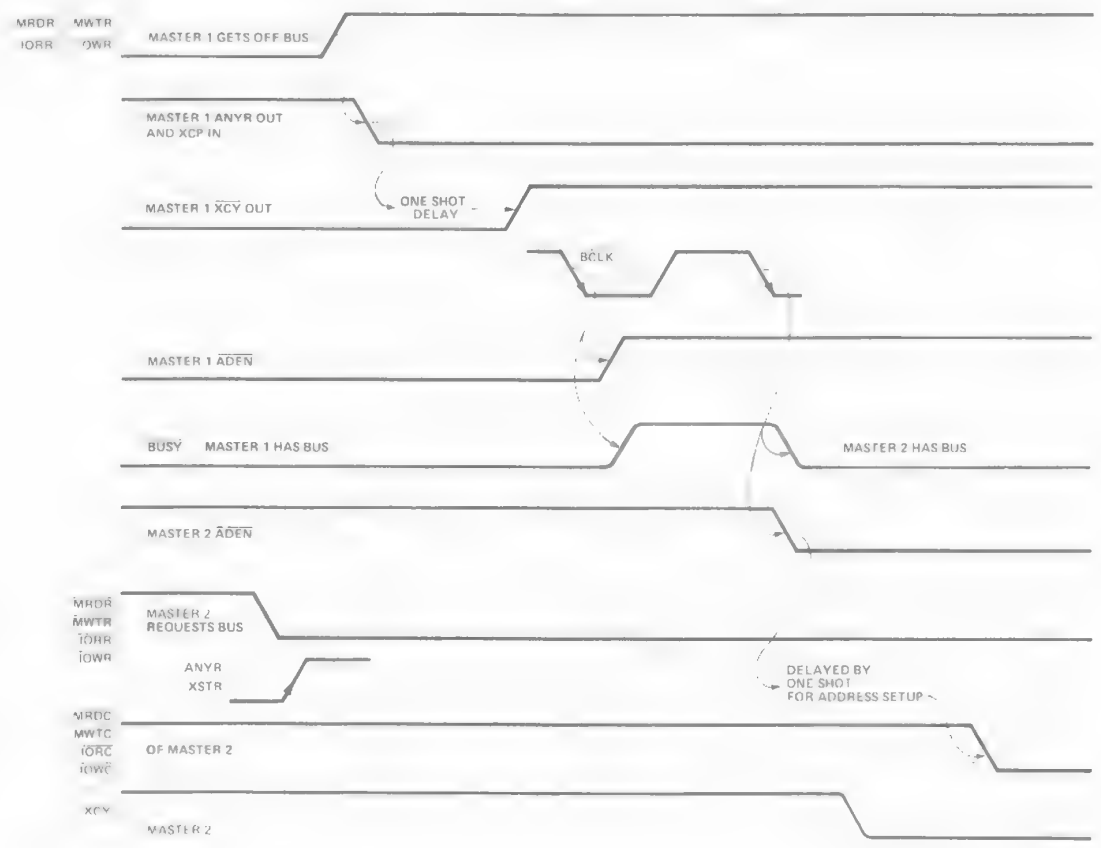


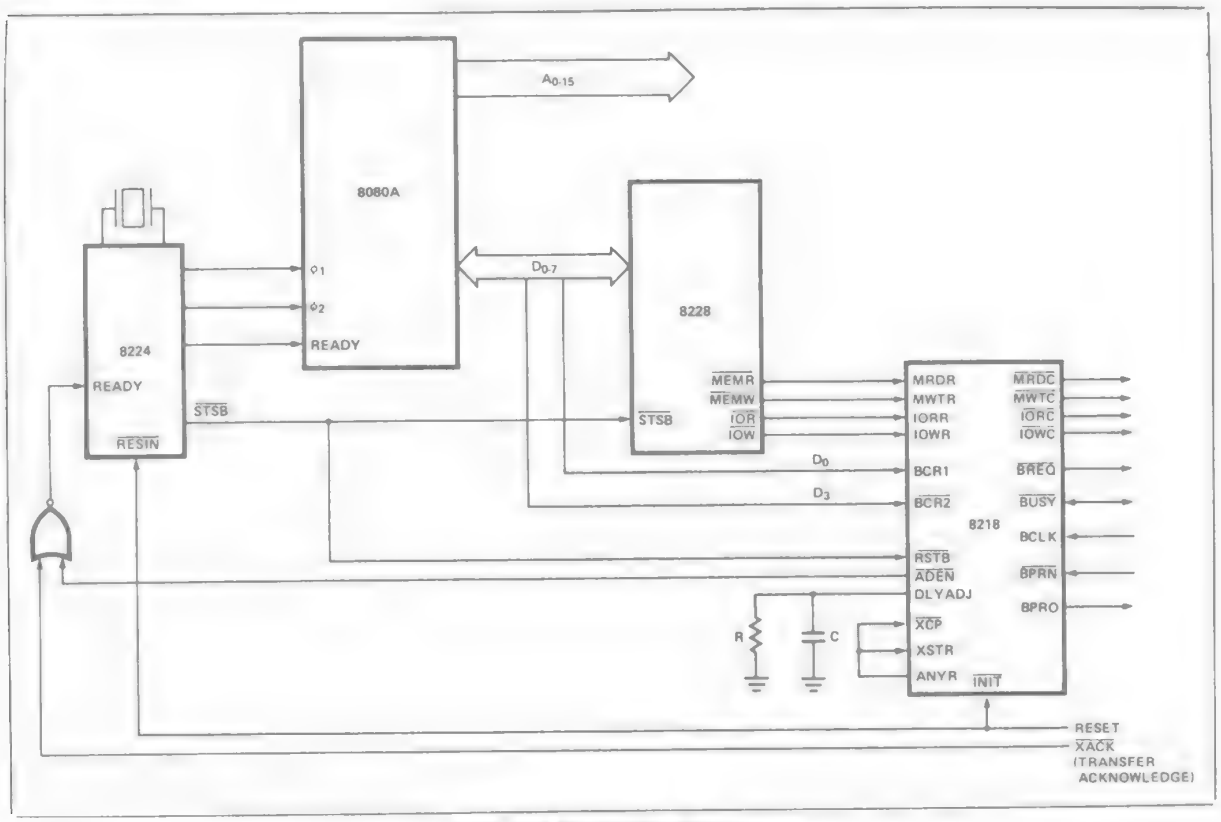
CONTROL CYCLE (System Bus Previously Not In Use)



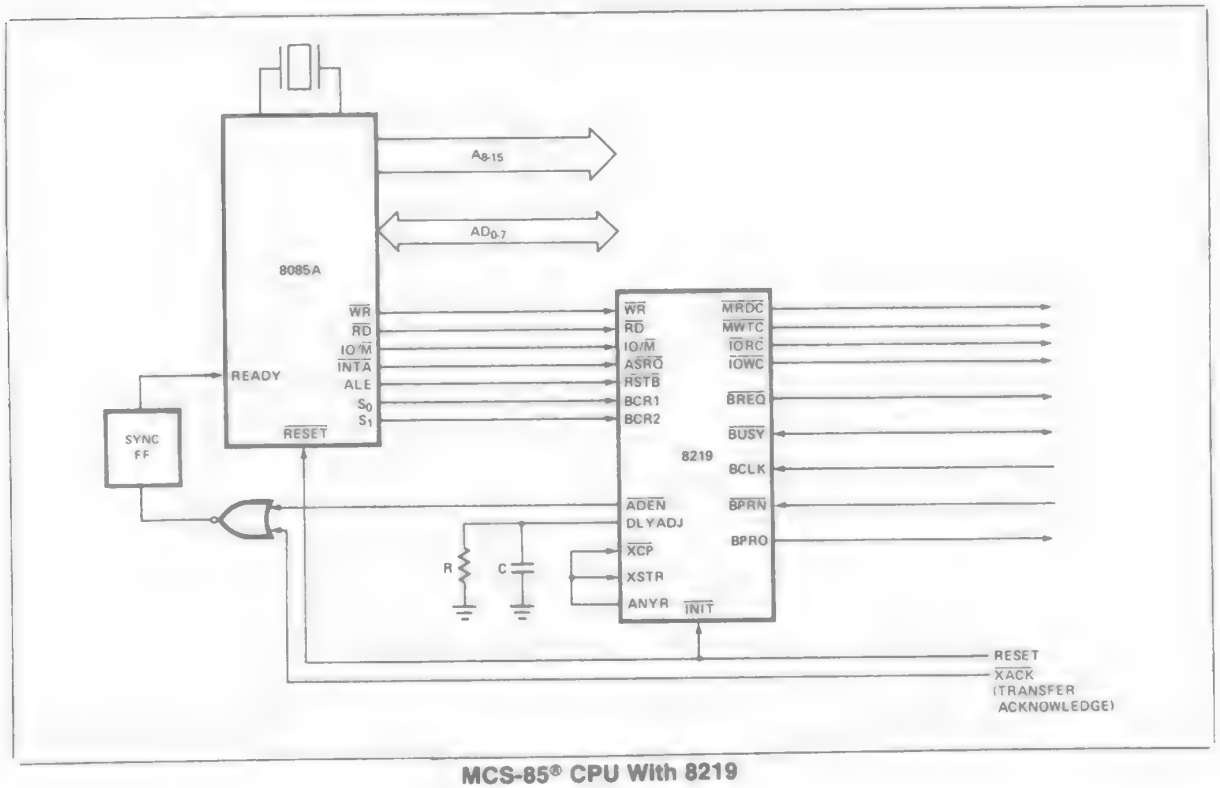
WAVEFORMS (Continued)

BUS CONTROL EXCHANGE (Master No. 1 Leaving Bus And Master No. 2 Getting On Bus)

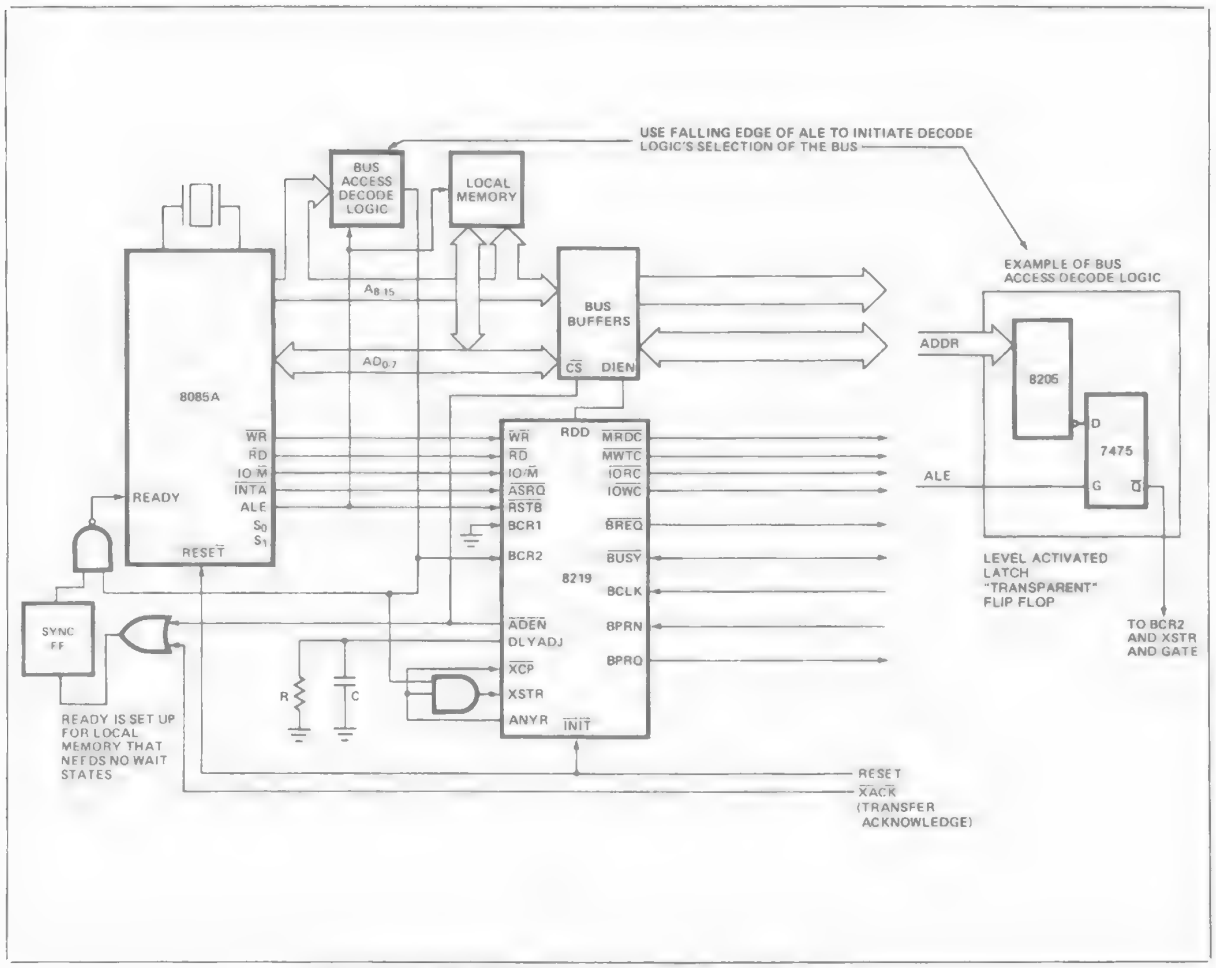




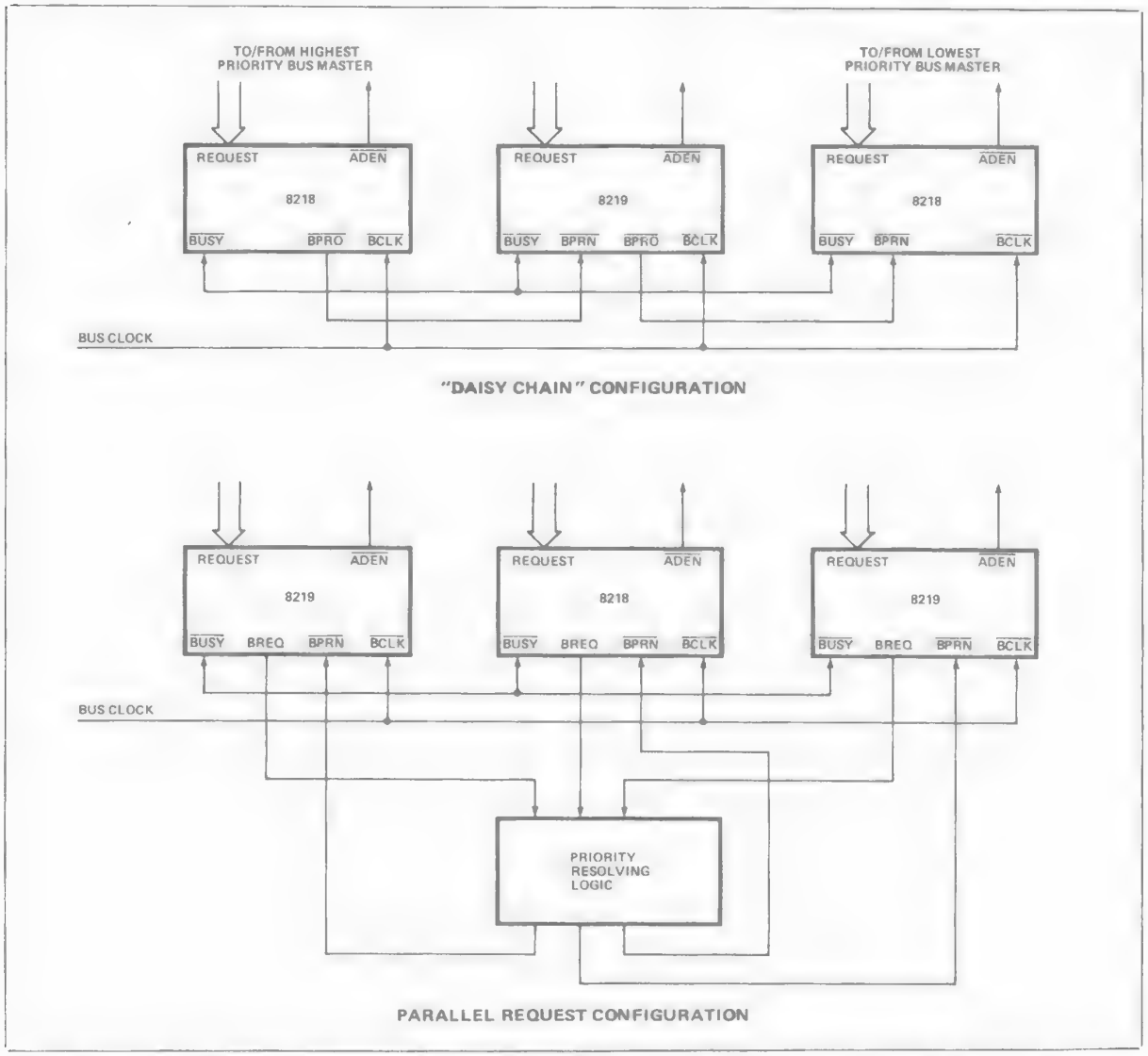
MCS-80® CPU With 8218



MCS-85® CPU With 8219



MCS-85® CPU With 8219 Using Local Memory



Two Methods of Connecting Multiple 8218/8219's To Resolve Bus Contention Among Multiple Masters

8224
CLOCK GENERATOR AND DRIVER FOR 8080A CPU

- **Single Chip Clock Generator/Driver for 8080A CPU**
- **Power-Up Reset for CPU**
- **Ready Synchronizing Flip-Flop**
- **Advanced Status Strobe**
- **Oscillator Output for External System Timing**
- **Crystal Controlled for Stable System Operation**
- **Reduces System Package Count**
- **Available in EXPRESS – Standard Temperature Range**

The Intel® 8224 is a single chip clock generator/driver for the 8080A CPU. It is controlled by a crystal, selected by the designer to meet a variety of system speed requirements.

Also included are circuits to provide power-up reset, advance status strobe, and synchronization of ready.

The 8224 provides the designer with a significant reduction of packages used to generate clocks and timing for 8080A.

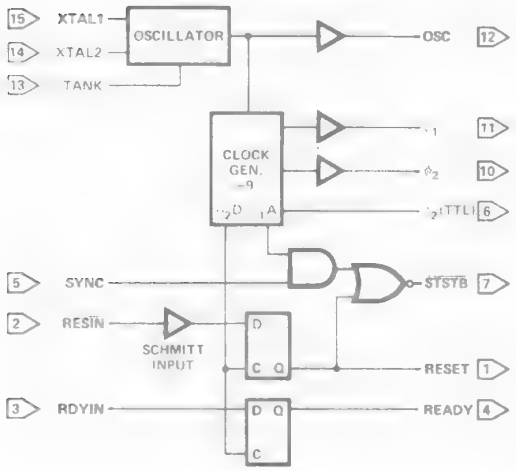
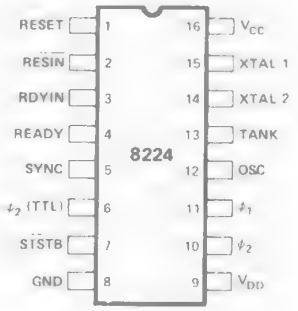


Figure 1. Block Diagram



RESIN	RESET INPUT
RESET	RESET OUTPUT
RDYIN	READY INPUT
READY	READY OUTPUT
SYNC	SYNC INPUT
STSTB	STATUS STB (ACTIVE LOW)
φ1	8080
φ2	CLOCKS

XTAL 1	CONNECTIONS FOR CRYSTAL
XTAL 2	
TANK	USED WITH OVERTONE XTAL
OSC	OSCILLATOR OUTPUT
φ2 (TTL)	φ2 CLK (TTL LEVEL)
VCC	+5V
VDD	+12V
GND	0V

Figure 2. Pin Configuration

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias . . . . . 0°C to 70°C
Storage Temperature . . . . . –65°C to 150°C
Supply Voltage, V_{CC} . . . . . –0.5V to +7V
Supply Voltage, V_{DD} . . . . . –0.5V to +13.5V
Input Voltage . . . . . –1.5V to +7V
Output Current 100mA

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = +5.0V ±5%, V_{DD} = +12V ±5%)

Symbol	Parameter	Limits Min.	Limits Typ.	Limits Max.	Units	Test Conditions
I_F	Input Current Loading			-.25	mA	V_F = .45V
I_R	Input Leakage Current			10	μA	V_R = 5.25V
V_C	Input Forward Clamp Voltage			1.0	V	I_C = -5mA
V_{IL}	Input "Low" Voltage			.8	V	V_{CC} = 5.0V
V_{IH}	Input "High" Voltage	2.6 2.0			V	Reset Input All Other Inputs
V_{IH}-V_{IL}	RESIN Input Hysteresis	.25			V	V_{CC} = 5.0V
V_{OL}	Output "Low" Voltage			.45 .45	V V	(ϕ_1,ϕ_2), Ready, Reset, $\overline{STSTB}$ I_{OL} =2.5mA All Other Outputs I_{OL} = 15mA
V_{OH}	Output "High" Voltage ϕ_1 , ϕ_2 READY, RESET All Other Outputs	 9.4 3.6 2.4			 V V V	 I_{OH} = -100μA I_{OH} = -100μA I_{OH} = -1mA
I_{SC}[1]	Output Short Circuit Current (All Low Voltage Outputs Only)	-10		-60	mA	V_O = 0V V_{CC} = 5.0V
I_{CC}	Power Supply Current			115	mA	
I_{DD}	Power Supply Current			12	mA	

Note: 1. Caution, ϕ_1 and ϕ_2 output drivers do not have short circuit protection

Crystal Requirements

Tolerance: 0.005% at 0°C-70°C
Resonance: Series (Fundamental)*
Load Capacitance: 20-35 pF
Equivalent Resistance: 75-20 ohms
Power Dissipation (Min): 4 mW

*With tank circuit use 3rd overtone mode.

A.C. CHARACTERISTICS (V_{CC} = +5.0V ±5%, V_{DD} = +12.0V ±5%, T_A = 0°C to 70°C)

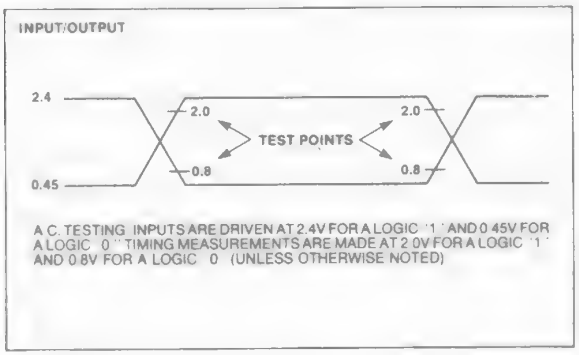
Symbol	Parameter	Limits Min.	Limits Typ.	Limits Max.	Units	Test Conditions
$t_{\phi 1}$	ϕ_1 Pulse Width	$\frac{2tcy}{9}$ - 20ns			ns	C_L = 20pF to 50pF
$t_{\phi 2}$	ϕ_2 Pulse Width	$\frac{5tcy}{9}$ - 35ns				
t_{D1}	ϕ_1 to ϕ_2 Delay	0				
t_{D2}	ϕ_2 to ϕ_1 Delay	$\frac{2tcy}{9}$ - 14ns				
t_{D3}	ϕ_1 to ϕ_2 Delay	$\frac{2tcy}{9}$		$\frac{2tcy}{9}$ + 20ns		
t_R	ϕ_1 and ϕ_2 Rise Time			20		
t_F	ϕ_1 and ϕ_2 Fall Time			20		
$t_{D\phi 2}$	ϕ_2 to ϕ_2 (TTL) Delay	-5		+15	ns	ϕ_2TTL,CL=30 R_1=300Ω R_2=600Ω
t_{DSS}	ϕ_2 to $\overline{STSTB}$ Delay	$\frac{6tcy}{9}$ - 30ns		$\frac{6tcy}{9}$		$\overline{STSTB}$,CL=15pF R_1 = 2K R_2 = 4K
t_{PW}	$\overline{STSTB}$ Pulse Width	$\frac{tcy}{9}$ - 15ns				
t_{DRS}	RDYIN Setup Time to Status Strobe	50ns - $\frac{4tcy}{9}$				
t_{DRH}	RDYIN Hold Time After $\overline{STSTB}$	$\frac{4tcy}{9}$				
t_{DR}	RDYIN or RESIN to ϕ_2 Delay	$\frac{4tcy}{9}$ - 25ns				Ready & Reset CL=10pF R_1=2K R_2=4K
t_{CLK}	CLK Period		$\frac{tcy}{9}$			
f_{max}	Maximum Oscillating Frequency			27	MHz	
C_{in}	Input Capacitance			8	pF	V_{CC}=+5.0V V_{DD}=+12V V_{BIAS}=2.5V f=1MHz

A.C. CHARACTERISTICS (Continued)

(For t_{CY} = 488.28 ns) (T_A = 0°C to 70°C, V_{DD} = +5V ±5%, V_{DD} = +12V ±5%)

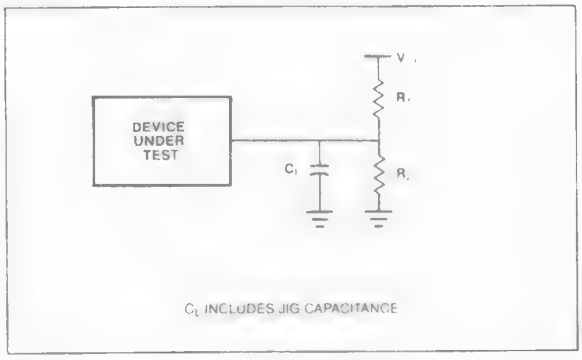
Symbol	Parameter	Limits Min.	Limits Typ.	Limits Max.	Units	Test Conditions
$t_{\phi 1}$	ϕ_1 Pulse Width	89			ns	t_{CY}=488.28ns
$t_{\phi 2}$	ϕ_2 Pulse Width	236			ns	
t_{D1}	Delay ϕ_1 to ϕ_2	0			ns	
t_{D2}	Delay ϕ_2 to ϕ_1	95			ns	ϕ_1 & ϕ_2 Loaded to C_L = 20 to 50pF
t_{D3}	Delay ϕ_1 to ϕ_2 Leading Edges	109		129	ns	
t_r	Output Rise Time			20	ns	
t_f	Output Fall Time			20	ns	
t_{DSS}	ϕ_2 to $\overline{STSTB}$ Delay	296		326	ns	
$t_{D\phi 2}$	ϕ_2 to ϕ_2 (TTL) Delay	-5		+15	ns	
t_{PW}	Status Strobe Pulse Width	40			ns	Ready & Reset Loaded to 2mA/10pF
t_{DRS}	RDYIN Setup Time to $\overline{STSTB}$	-167			ns	
t_{DRH}	RDYIN Hold Time after $\overline{STSTB}$	217			ns	All measurements referenced to 1.5V unless specified otherwise.
t_{DR}	READY or RESET to ϕ_2 Delay	192			ns	
f_{MAX}	Oscillator Frequency			18.432	MHz	

A.C. TESTING INPUT, OUTPUT WAVEFORM



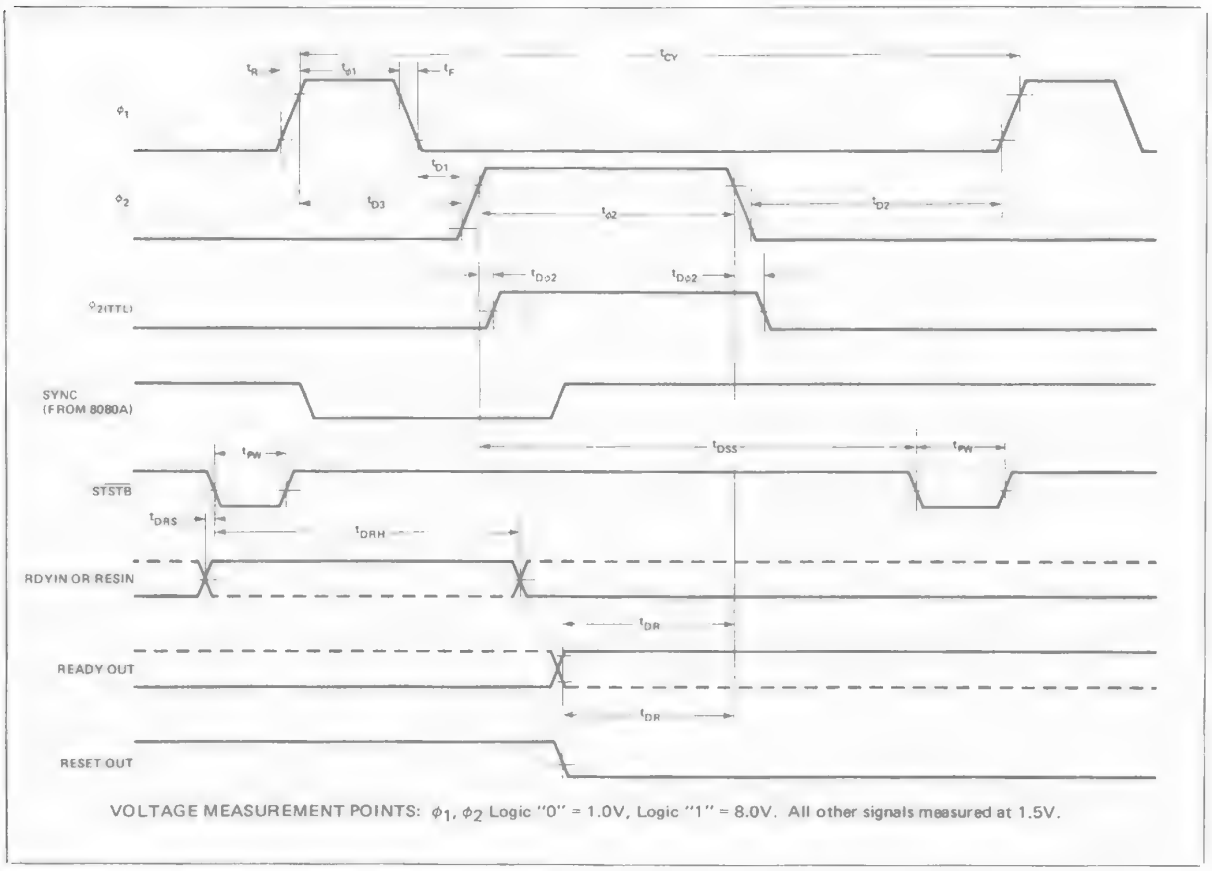
A.C. TESTING INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0". TIMING MEASUREMENTS ARE MADE AT 2.0V FOR A LOGIC "1" AND 0.8V FOR A LOGIC "0" (UNLESS OTHERWISE NOTED)

A.C. TESTING LOAD CIRCUIT



C_L INCLUDES JIG CAPACITANCE

WAVEFORMS



VOLTAGE MEASUREMENT POINTS: ϕ_1, ϕ_2 Logic "0" = 1.0V, Logic "1" = 8.0V. All other signals measured at 1.5V.

8228/8238
SYSTEM CONTROLLER AND BUS DRIVER FOR 8080A CPU

- **Single Chip System Control for MCS-80® Systems**
- **Built-In Bidirectional Bus Driver for Data Bus Isolation**
- **Allows the Use of Multiple Byte Instructions (e.g. CALL) for Interrupt Acknowledge**
- **User Selected Single Level Interrupt Vector (RST 7)**
- **28-Pin Dual In-Line Package**
- **Reduces System Package Count**
- **8238 Had Advanced IOW/MEMW for Large System Timing Control**
- **Available in EXPRESS – Standard Temperature Range**

The Intel® 8228 is a single chip system controller and bus driver for MCS-80. It generates all signals required to directly interface MCS-80 family RAM, ROM, and I/O components.

A bidirectional bus driver is included to provide high system TTL fan-out. It also provides isolation of the 8080 data bus from memory and I/O. This allows for the optimization of control signals, enabling the systems designer to use slower memory and I/O. The isolation of the bus driver also provides for enhanced system noise immunity.

A user selected single level interrupt vector (RST 7) is provided to simplify real time, interrupt driven, small system requirements. The 8228 also generates the correct control signals to allow the use of multiple byte instructions (e.g., CALL) in response to an interrupt acknowledge by the 8080A. This feature permits large, interrupt driven systems to have an unlimited number of interrupt levels.

The 8228 is designed to support a wide variety of system bus structures and also reduce system package count for cost effective, reliable design of the MCS-80 systems.

Note: The specifications for the 3228/3238 are identical with those for the 8228/8238

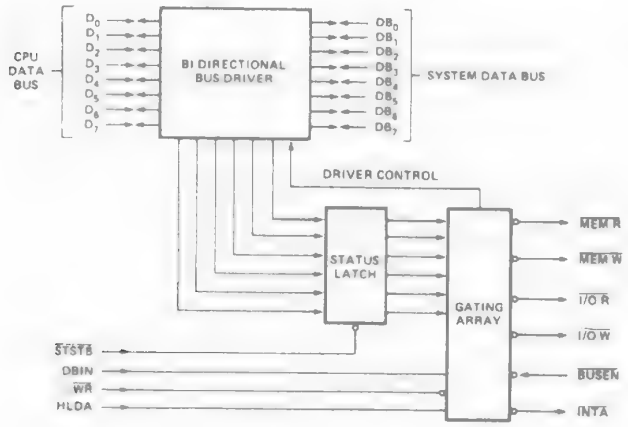
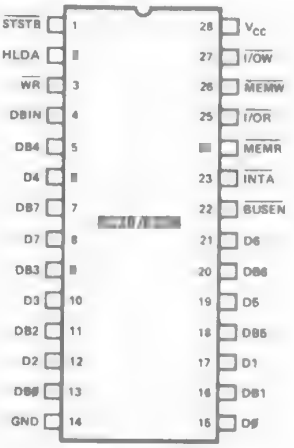


Figure 1. Block Diagram



D7-D0	DATA BUS (8080 SIDE)	INTA	INTERRUPT ACKNOWLEDGE
DB7-DB0	DATA BUS (SYSTEM SIDE)	HLDA	HLDA (FROM 8080)
$\overline{I/OR}$	I/O READ	$\overline{WR}$	WR (FROM 8080)
$\overline{I/OW}$	I/O WRITE	$\overline{BUSEN}$	BUS ENABLE INPUT
$\overline{MEMR}$	MEMORY READ	$\overline{STSTB}$	STATUS STROBE (FROM 8224)
$\overline{MEMW}$	MEMORY WRITE	V_{CC}	+5V
DBIN	DBIN (FROM 8080)	GND	0 VOLTS

Figure 2. Pin Configuration

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias . . . . . – 0°C to 70°C
Storage Temperature . . . . . – 65°C to 150°C
Supply Voltage, V_{CC} . . . . . – 0.5V to + 7V
Input Voltage . . . . . – 1.5V to + 7V
Output Current . . . . . 100 mA

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not limited. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ±5%)

Symbol	Parameter	Limits Min.	Limits Typ.[1]	Limits Max.	Unit	Test Conditions
V_C	Input Clamp Voltage, All Inputs		.75	-1.0	V	V_{CC}=4.75V; I_C=-5mA
I_F	Input Load Current, $\overline{STSTB}$			500	μA	V_{CC} = 5.25V
	D_2 & D_6			750	μA	V_F = 0.45V
	D_0, D_1, D_4, D_5, & D_7			250	μA	
	All Other Inputs			250	μA	
I_R	Input Leakage Current $\overline{STSTB}$			100	μA	V_{CC} = 5.25V
	DB_0-DB_7			20	μA	V_R = 5.25V
	All Other Inputs			100	μA	
V_{TH}	Input Threshold Voltage, All Inputs	0.8		2.0	V	V_{CC} = 5V
I_{CC}	Power Supply Current		140	190	mA	V_{CC}=5.25V
V_{OL}	Output Low Voltage, D_0-D_7			.45	V	V_{CC}=4.75V; I_{OL}=2mA
	All Other Outputs			.45	V	I_{OL} = 10mA
V_{OH}	Output High Voltage, D_0-D_7	3.6	3.8		V	V_{CC}=4.75V; I_{OH}=-10μA
	All Other Outputs	2.4			V	I_{OH} = -1mA
I_{OS}	Short Circuit Current, All Outputs	15		90	mA	V_{CC}=5V
$I_{O(off)}$	Off State Output Current, All Control Outputs			100	μA	V_{CC}=5.25V; V_O=5.25
				-100	μA	V_O=.45V
I_{INT}	INTA Current			5	mA	(See INTA Test Circuit)

Note 1: Typical values are for T_A = 25°C and nominal supply voltages.

CAPACITANCE (V_{BIAS} = 2.5V, V_{CC} = 5.0V, T_A = 25°C, f = 1 MHz)

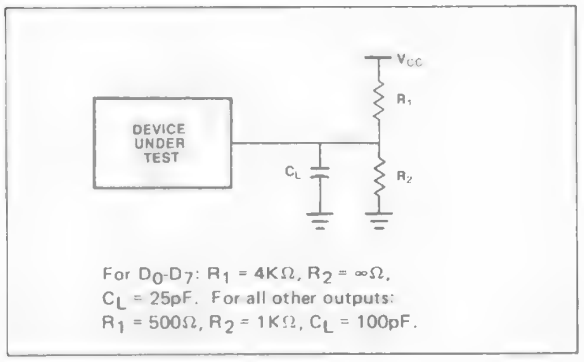
This parameter is periodically sampled and not 100% tested.

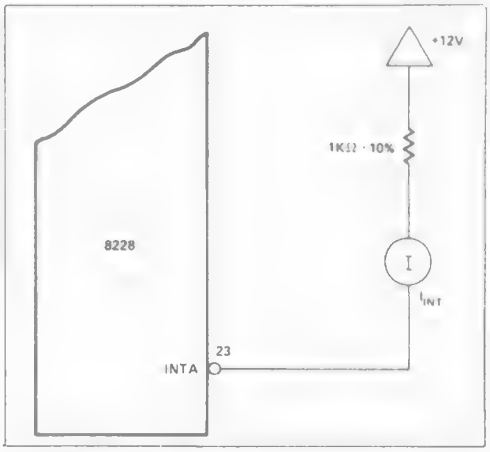
Symbol	Parameter	Limits Min.	Typ.[1]	Max.	Unit
C_{IN}	Input Capacitance		8	12	pF
C_{OUT}	Output Capacitance Control Signals		7	15	pF
I/O	I/O Capacitance (D or DB)		8	15	pF

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ±5%)

Symbol	Parameter	Limits Min.	Max.	Units	Condition
t_{PW}	Width of Status Strobe	22		ns	
t_{SS}	Setup Time, Status Inputs D_0-D_7	[illegible]		ns	
t_{SH}	Hold Time, Status Inputs D_0-D_7	5		ns	
t_{DC}	Delay from $\overline{STSTB}$ to any Control Signal	20	60	ns	C_L = 100pF
t_{RR}	Delay from DBIN to Control Outputs		30	ns	C_L = 100pF
t_{RE}	Delay from DBIN to Enable/Disable 8080 Bus		45	ns	C_L = 25pF
t_{RD}	Delay from System Bus to 8080 Bus during Read		30	ns	C_L = 25pF
t_{WR}	Delay from $\overline{WR}$ to Control Outputs	[illegible]	45	ns	C_L = 100pF
t_{WE}	Delay to Enable System Bus DB_0-DB_7 after $\overline{STSTB}$		30	ns	C_L = 100pF
t_{WD}	Delay from 8080 Bus D_0-D_7 to System Bus DB_0-DB_7 during Write	5	40	ns	C_L = 100pF
t_E	Delay from $\overline{\text{System Bus Enable}}$ to System Bus DB_0-DB_7		30	ns	C_L = 100pF
t_{HD}	HLDA to Read Status Outputs		25	ns	
t_{DS}	Setup Time, System Bus Inputs to HLDA	10		ns	
t_{DH}	Hold Time, System Bus Inputs to HLDA	20		ns	C_L = 100pF

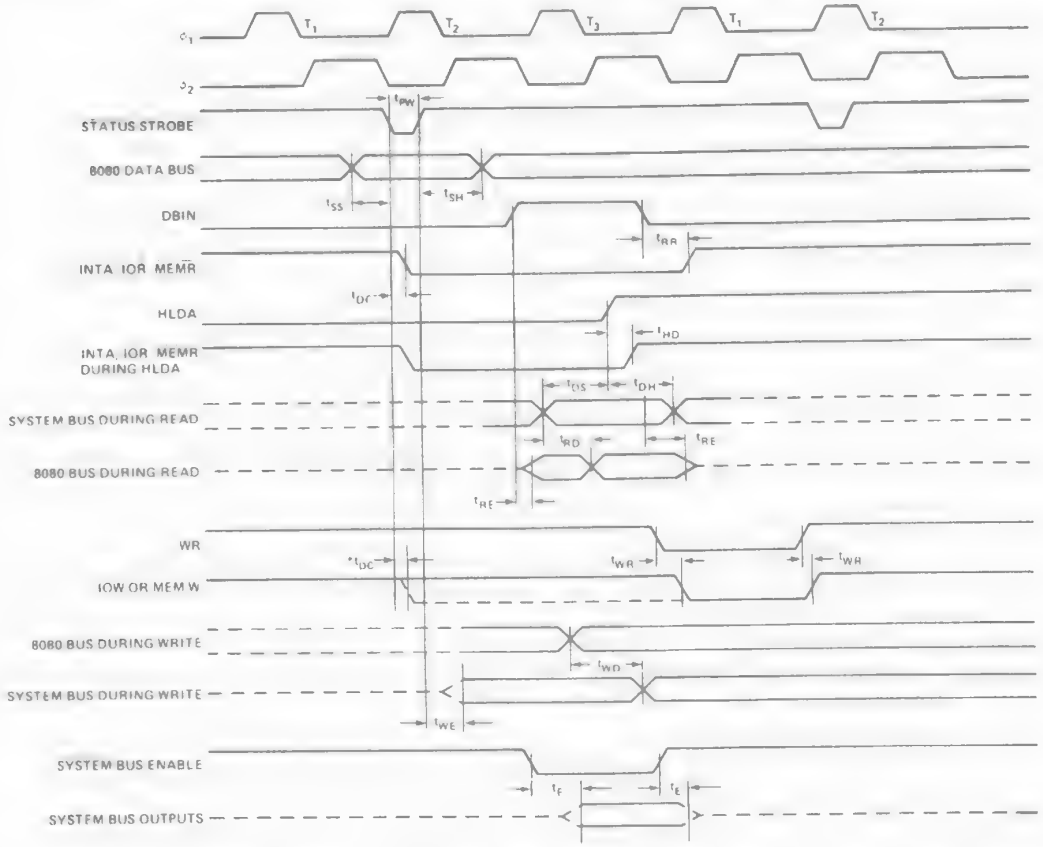
A.C. TESTING LOAD CIRCUIT





INTA Test Circuit (for RST 7)

WAVEFORM



VOLTAGE MEASUREMENT POINTS: D_0-D_7 (when outputs) Logic "0" = 0.8V, Logic "1" = 3.0V. All other signals measured at 1.5V.

*ADVANCED $\overline{IOW}$/$\overline{MEMW}$ FOR 8238 ONLY.

8237A/8237A-4/8237A-5 HIGH PERFORMANCE PROGRAMMABLE DMA CONTROLLER

- Enable/Disable Control of Individual DMA Requests
- Four Independent DMA Channels
- Independent Autoinitialization of all Channels
- Memory-to-Memory Transfers
- Memory Block Initialization
- Address Increment or Decrement
- High performance: Transfers up to 1.6M Bytes/Second with 5 MHz 8237A-5
- Directly Expandable to any Number of Channels
- End of Process Input for Terminating Transfers
- Software DMA Requests
- Independent Polarity Control for DREQ and DACK Signals
- Available in EXPRESS
  - Standard Temperature Range

The 8237A Multimode Direct Memory Access (DMA) Controller is a peripheral interface circuit for microprocessor systems. It is designed to improve system performance by allowing external devices to directly transfer information from the system memory. Memory-to-memory transfer capability is also provided. The 8237A offers a wide variety of programmable control features to enhance data throughput and system optimization and to allow dynamic reconfiguration under program control.

The 8237A is designed to be used in conjunction with an external 8-bit address register such as the 8282. It contains four independent channels and may be expanded to any number of channels by cascading additional controller chips.

The three basic transfer modes allow programmability of the types of DMA service by the user. Each channel can be individually programmed to Autoinitialize to its original condition following an End of Process ($\overline{EOP}$).

Each channel has a full 64K address and word count capability.

The 8237A-4 and 8237A-5 are 4 MHz and 5 MHz selected versions of the standard 3 MHz 8237A respectively.

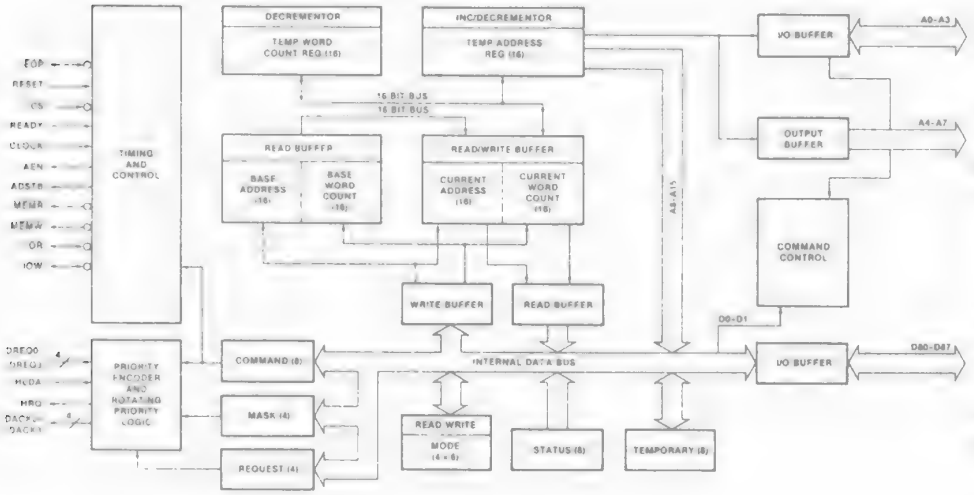


Figure 1. Block Diagram

Figure 2. Pin Configuration

Table 1. Pin Description

Symbol	Type	Name and Function
V_{CC}		**Power:** +5 volt supply.
V_{SS}		**Ground:** Ground.
CLK	I	**Clock Input:** Clock input controls the internal operations of the 8237A and its rate of data transfers. The input may be driven at up to 3 MHz for the standard 8237A and up to 5 MHz for the 8237A-5.
CS	I	**Chip Select:** Chip Select is an active low input used to select the 8237A as an I/O device during the Idle cycle. This allows CPU communication on the data bus.
RESET	I	**Reset:** Reset is an active high input which clears the Command, Status, Request and Temporary registers. It also clears the first/last flip/flop and sets the Mask register. Following a Reset the device is in the Idle cycle.
READY	I	**Ready:** Ready is an input used to extend the memory read and write pulses from the 8237A to accommodate slow memories or I/O peripheral devices. Ready must not make transitions during its specified setup/hold time.
HLDA	I	**Hold Acknowledge:** The active high Hold Acknowledge from the CPU indicates that it has relinquished control of the system busses.
DREQ0-DREQ3	I	**DMA Request:** The DMA Request lines are individual asynchronous channel request inputs used by peripheral circuits to obtain DMA service. In fixed Priority, DREQ0 has the highest priority and DREQ3 has the lowest priority. A request is generated by activating the DREQ line of a channel. DACK will acknowledge the recognition of DREQ signal. Polarity of DREQ is programmable. Reset intializes these lines to active high. DREQ must be maintained until the corresponding DACK goes active.
DB0-DB7	I/O	**Data Bus:** The Data Bus lines are bidirectional three-state signals connected to the system data bus. The outputs are enabled in the Program condition during the I/O Read to output the contents of an Address register, a Status register, the Temporary register or a Word Count register to the CPU. The outputs are disabled and the inputs are read during an I/O Write cycle when the CPU is programming the 8237A control registers. During DMA cycles the most significant 8 bits of the address are output onto the data bus to be strobed into an external latch by ADSTB. In memory-to-memory operations, data from the memory comes into the 8237A on the data bus during the read-from-memory transfer. In the write-to-memory transfer, the data bus outputs place the data into the new memory location.
$\overline{IOR}$	I/O	**I/O Read:** I/O Read is a bidirectional active low three-state line. In the Idle cycle, it is an input control signal used by the CPU to read the control registers. In the Active cycle, it is an output control signal used by the 8237A to access data from a peripheral during a DMA Write transfer.
$\overline{IOW}$	I/O	**I/O Write:** I/O Write is a bidirectional active low three-state line. In the Idle cycle, it is an input control signal used by the CPU to load information into the 8237A. In the Active cycle, it is an output control signal used by the 8237A to load data to the peripheral during a DMA Read transfer.
$\overline{EOP}$	I/O	**End of Process:** End of Process is an active low bidirectional signal. Information concerning the completion of DMA services is available at the bidirectional $\overline{EOP}$ pin. The 8237A allows an external signal to terminate an active DMA service. This is accomplished by pulling the $\overline{EOP}$ input low with an external $\overline{EOP}$ signal. The 8237A also generates a pulse when the terminal count (TC) for any channel is reached. This generates an $\overline{EOP}$ signal which is output through the $\overline{EOP}$ Line. The reception of $\overline{EOP}$, either internal or external, will cause the 8237A to terminate the service, reset the request, and, if Autoinitialize is enabled, to write the base registers to the current registers of that channel. The mask bit and TC bit in the status word will be set for the currently active channel by $\overline{EOP}$ unless the channel is programmed for Autoinitialize. In that case, the mask bit remains clear. During memory-to-memory transfers, $\overline{EOP}$ will be output when the TC for channel 1 occurs. $\overline{EOP}$ should be tied high with a pull-up resistor if it is not used to prevent erroneous end of process inputs.
A0-A3	I/O	**Address:** The four least significant address lines are bidirectional three-state signals. In the Idle cycle they are inputs and are used by the 8237A to address the control register to be loaded or read. In the Active cycle they are outputs and provide the lower 4 bits of the output address.

Table 1. Pin Description (Continued)

Symbol	Type	Name and Function
A4-A7	O	**Address:** The four most significant address lines are three-state outputs and provide 4 bits of address. These lines are enabled only during the DMA service.
HRQ	O	**Hold Request:** This is the Hold Request to the CPU and is used to request control of the system bus. If the corresponding mask bit is clear, the presence of any valid DREQ causes 8237A to issue the HRQ. After HRQ goes active at least one clock cycle (TCY) must occur before HLDA goes active.
DACK0-DACK3	O	**DMA Acknowledge:** DMA Acknowledge is used to notify the individual peripherals when one has been granted a DMA cycle. The sense of these lines is programmable. Reset initializes them to active low.
AEN	O	**Address Enable:** Address Enable enables the 8-bit latch containing the upper 8 address bits onto the system address bus. AEN can also be used to disable other system bus drivers during DMA transfers. AEN is active HIGH.
ADSTB	O	**Address Strobe:** The active high, Address Strobe is used to strobe the upper address byte into an external latch.
$\overline{\text{MEMR}}$	O	**Memory Read:** The Memory Read signal is an active low three-state output used to access data from the selected memory location during a DMA Read or a memory-to-memory transfer.
$\overline{\text{MEMW}}$	O	**Memory Write:** The Memory Write is an active low three-state output used to write data to the selected memory location during a DMA Write or a memory-to-memory transfer.

FUNCTIONAL DESCRIPTION

The 8237A block diagram includes the major logic blocks and all of the internal registers. The data interconnection paths are also shown. Not shown are the various control signals between the blocks. The 8237A contains 344 bits of internal memory in the form of registers. Figure 3 lists these registers by name and shows the size of each. A detailed description of the registers and their functions can be found under Register Description.

Name	Size	Number
Base Address Registers	16 bits	4
Base Word Count Registers	16 bits	4
Current Address Registers	16 bits	4
Current Word Count Registers	16 bits	4
Temporary Address Register	16 bits	1
Temporary Word Count Register	16 bits	1
Status Register	8 bits	1
Command Register	8 bits	1
Temporary Register	8 bits	1
Mode Registers	6 bits	4
Mask Register	4 bits	1
Request Register	4 bits	1

Figure 3. 8237A Internal Registers

The 8237A contains three basic blocks of control logic. The Timing Control block generates internal timing and external control signals for the 8237A. The Program Command Control block decodes the various commands given to the 8237A by the microprocessor prior to servicing a DMA Request. It also decodes the Mode Control word used to select the type of DMA during the servicing. The Priority Encoder block resolves priority contention between DMA channels requesting service simultaneously.

The Timing Control block derives internal timing from the clock input. In 8237A systems this input will usually be the $\phi 2$ TTL clock from an 8224 or CLK from an 8085AH or 8284A. For 8085AH-2 systems above 3.9 MHz, the 8085 CLK(OUT) does not satisfy 8237A-5 clock LOW and HIGH time requirements. In this case, an external clock should be used to drive the 8237A-5.

DMA Operation

The 8237A is designed to operate in two major cycles. These are called Idle and Active cycles. Each device cycle is made up of a number of states. The 8237A can assume seven separate states, each composed of one full clock period. State I (SI) is the inactive state. It is entered when the 8237A has no valid DMA requests pending. While in SI, the DMA controller is inactive but may be in the Program Condition, being programmed by the processor. State S0 (S0) is the first state of a DMA service. The 8237A has requested a hold but the processor has not yet returned an acknowledge. The 8237A may still be programmed until it receives HLDA from the CPU. An acknowledge from the CPU will signal that DMA transfers may begin. S1, S2, S3 and S4 are the working states of the DMA service. If more time is needed to complete a transfer than is available with normal timing, wait states (SW) can be inserted between S2 or S3 and S4 by the use of the Ready line on the 8237A. Note that the data is transferred directly from the I/O device to memory (or vice versa) with $\overline{\text{IOR}}$ and $\overline{\text{MEMW}}$ (or $\overline{\text{MEMR}}$ and $\overline{\text{IOW}}$) being active at the same time. The data is not read into or driven out of the 8237A in I/O-to-memory or memory-to-I/O DMA transfers.

Memory-to-memory transfers require a read-from and a write-to-memory to complete each transfer. The states, which resemble the normal working states, use two digit numbers for identification. Eight states are required for a single transfer. The first four states (S11, S12, S13, S14) are used for the read-from-memory half

and the last four states (S21, S22, S23, S24) for the write-to-memory half of the transfer.

IDLE CYCLE

When no channel is requesting service, the 8237A will enter the Idle cycle and perform "SI" states. In this cycle the 8237A will sample the DREQ lines every clock cycle to determine if any channel is requesting a DMA service. The device will also sample $\overline{CS}$, looking for an attempt by the microprocessor to write or read the internal registers of the 8237A. When $\overline{CS}$ is low and HLDA is low, the 8237A enters the Program Condition. The CPU can now establish, change or inspect the internal definition of the part by reading from or writing to the internal registers. Address lines A0–A3 are inputs to the device and select which registers will be read or written. The $\overline{IOR}$ and $\overline{IOW}$ lines are used to select and time reads or writes. Due to the number and size of the internal registers, an internal flip-flop is used to generate an additional bit of address. This bit is used to determine the upper or lower byte of the 16-bit Address and Word Count registers. The flip-flop is reset by Master Clear or Reset. A separate software command can also reset this flip-flop.

Special software commands can be executed by the 8237A in the Program Condition. These commands are decoded as sets of addresses with the $\overline{CS}$ and $\overline{IOW}$. The commands do not make use of the data bus. Instructions include Clear First/Last Flip-FLop and Master Clear.

ACTIVE CYCLE

When the 8237A is in the Idle cycle and a non-masked channel requests a DMA service, the device will output an HRQ to the microprocessor and enter the Active cycle. It is in this cycle that the DMA service will take place, in one of four modes:

Single Transfer Mode — In Single Transfer mode the device is programmed to make one transfer only. The word count will be decremented and the address decremented or incremented following each transfer. When the word count "rolls over" from zero to FFFFH, a Terminal Count (TC) will cause an Autoinitialize if the channel has been programmed to do so.

DREQ must be held active until DACK becomes active in order to be recognized. If DREQ is held active throughout the single transfer, HRQ will go inactive and release the bus to the system. It will again go active and, upon receipt of a new HLDA, another single transfer will be performed, in 8080A, 8085AH, 8088, or 8086 system this will ensure one full machine cycle execution between DMA transfers. Details of timing between the 8237A and other bus control protocols will depend upon the characteristics of the microprocessor involved.

Block Transfer Mode — In Block Transfer mode the device is activated by DREQ to continue making transfers during the service until a TC, caused by word count going to FFFFH, or an external End of Process ($\overline{EOP}$) is encountered. DREQ need only be held active until DACK becomes active. Again, an Autoinitialization will occur at the end of the service if the channel has been programmed for it.

Demand Transfer Mode — In Demand Transfer mode the device is programmed to continue making transfers until a TC or external $\overline{EOP}$ is encountered or until DREQ goes inactive. Thus transfers may continue until the I/O device has exhausted its data capacity. After the I/O device has had a chance to catch up, the DMA service is re-established by means of a DREQ. During the time between services when the microprocessor is allowed to operate, the intermediate values of address and word count are stored in the 8237A Current Address and Current Word Count registers. Only an $\overline{EOP}$ can cause an Autoinitialize at the end of the service. $\overline{EOP}$ is generated either by TC or by an external signal.

Cascade Mode — This mode is used to cascade more than one 8237A together for simple system expansion. The HRQ and HLDA signals from the additional 8237A are connected to the DREQ and DACK signals of a channel of the initial 8237A. This allows the DMA requests of the additional device to propagate through the priority network circuitry of the preceding device. The priority chain is preserved and the new device must wait for its turn to acknowledge requests. Since the cascade channel of the initial 8237A is used only for prioritizing the additional device, it does not output any address or control signals of its own. These could conflict with the outputs of the active channel in the added device. The 8237A will respond to DREQ and DACK but all other outputs except HRQ will be disabled.

Figure 4 shows two additional devices cascaded into an initial device using two of the previous channels. This forms a two level DMA system. More 8237As could be added at the second level by using the remaining channels of the first level. Additional devices can also be added by cascading into the channels of the second level devices, forming a third level.

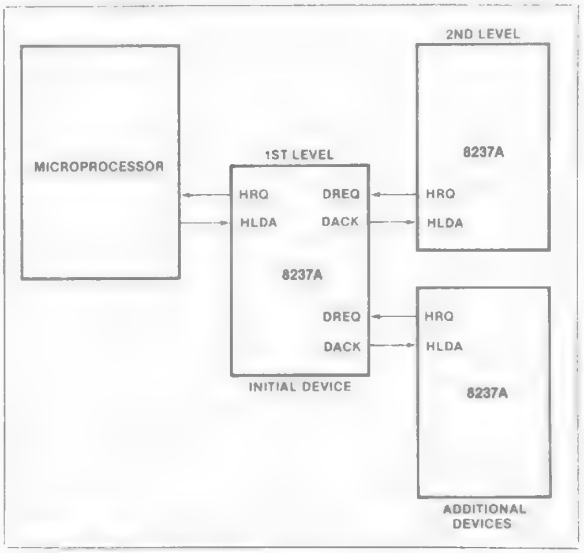


Figure 4. Cascaded 8237As

TRANSFER TYPES

Each of the three active transfer modes can perform three different types of transfers. These are Read, Write and Verify. Write transfers move data from an I/O device to the memory by activating $\overline{MEMW}$ and $\overline{IOR}$. Read transfers move data from memory to an I/O device by activating $\overline{MEMR}$ and $\overline{IOW}$. Verify transfers are pseudo transfers. The 8237A operates as in Read or Write transfers generating addresses, and responding to EOP, etc. However, the memory and I/O control lines all remain inactive. Verify mode is not permitted during memory to memory operation.

Memory-to-Memory — To perform block moves of data from one memory address space to another with a minimum of program effort and time, the 8237A includes a memory-to-memory transfer feature. Programming a bit in the Command register selects channels 0 and 1 to operate as memory-to-memory transfer channels. The transfer is initiated by setting the software DREQ for channel 0. The 8237A requests a DMA service in the normal manner. After HLDA is true, the device, using eight-state transfers in Block Transfer mode, reads data from the memory. The channel 0 Current Address register is the source for the address used and is decremented or incremented in the normal manner. The data byte read from the memory is stored in the 8237A internal Temporary register. Channel 1 then writes the data from the Temporary register to memory using the address in its Current Address register and incrementing or decrementing it in the normal manner. The channel 1 Current Word Count is decremented. When the word count of channel 1 goes to FFFFH, a TC is generated causing an $\overline{EOP}$ output terminating the service.

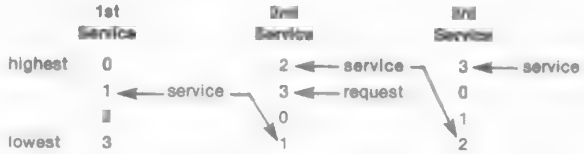
Channel 0 may be programmed to retain the same address for all transfers. This allows a single word to be written to a block of memory.

The 8237A will respond to external $\overline{EOP}$ signals during memory-to-memory transfers. Data comparators in block search schemes may use this input to terminate the service when a match is found. The timing of memory-to-memory transfers is found in Figure 12. Memory-to-memory operations can be detected as an active AEN with no DACK outputs.

Autoinitialize — By programming a bit in the Mode register, a channel may be set up as an Autoinitialize channel. During Autoinitialize Initialization, the original values of the Current Address and Current Word Count registers are automatically restored from the Base Address and Base Word count registers of that channel following $\overline{EOP}$. The base registers are loaded simultaneously with the current registers by the microprocessor and remain unchanged throughout the DMA service. The mask bit is not set when the channel is in Autoinitialize. Following Autoinitialize the channel is ready to perform another DMA service, without CPU intervention, as soon as a valid DREQ is detected.

Priority — The 8237A has two types of priority encoding available as software selectable options. The first is Fixed Priority which fixes the channels in priority order based upon the descending value of their number. The channel with the lowest priority is 3 followed by 2, 1 and the highest priority channel, 0. After the recognition of any one channel for service, the other channels are prevented from interferring with that service until it is completed.

The second scheme is Rotating Priority. The last channel to get service becomes the lowest priority channel with the others rotating accordingly.



With Rotating Priority in a single chip DMA system, any device requesting service is guaranteed to be recognized after no more than three higher priority services have occurred. This prevents any one channel from monopolizing the system.

Compressed Timing — In order to achieve even greater throughput where system characteristics permit, the 8237A can compress the transfer time to two clock cycles. From Figure 11 it can be seen that state S3 is used to extend the access time of the read pulse. By removing state S3, the read pulse width is made equal to the write pulse width and a transfer consists only of state S2 to change the address and state S4 to perform the read/write. S1 states will still occur when A8–A15 need updating (see Address Generation). Timing for compressed transfers is found in Figure 14.

Address Generation — In order to reduce pin count, the 8237A multiplexes the eight higher order address bits on the data lines. State S1 is used to output the higher order address bits to an external latch from which they may be placed on the address bus. The falling edge of Address Strobe (ADSTB) is used to load these bits from the data lines to the latch. Address Enable (AEN) is used to enable the bits onto the address bus through a three-state enable. The lower order address bits are output by the 8237A directly. Lines A0–A7 should be connected to the address bus. Figure 11 shows the time relationships between CLK, AEN, ADSTB, DB0–DB7 and A0–A7.

During Block and Demand Transfer mode services, which include multiple transfers, the addresses generated will be sequential. For many transfers the data held in the external address latch will remain the same. This data need only change when a carry or borrow from A7 to A8 takes place in the normal sequence of addresses. To save time and speed transfers, the 8237A executes S1 states only when updating of A8–A15 in the latch is necessary. This means for long services, S1 states and Address Strobes may occur only once every 256 transfers, a savings of 255 clock cycles for each 256 transfers.

REGISTER DESCRIPTION

Current Address Register — Each channel has a 16-bit Current Address register. This register holds the value of the address used during DMA transfers. The address is automatically incremented or decremented after each transfer and the intermediate values of the address are stored in the Current Address register during the transfer. This register is written or read by the microprocessor in successive 8-bit bytes. It may also be reinitialized by an Autoinitialize back to its original value. Autoinitialize takes place only after an $\overline{EOP}$.

Current Word Register — Each channel has a 16-bit Current Word Count register. This register determines the number of transfers to be performed. The actual number of transfers will be one more than the number programmed in the Current Word Count register (i.e., programming a count of 100 will result in 101 transfers). The word count is decremented after each transfer. The intermediate value of the word count is stored in the register during the transfer. When the value in the register goes from zero to FFFFH, a TC will be generated. This register is loaded or read in successive 8-bit bytes by the microprocessor in the Program Condition. Following the end of a DMA service it may also be reinitialized by an Autoinitialization back to its original value. Autoinitialize can occur only when an $\overline{EOP}$ occurs. If it is not Autoinitialized, this register will have a count of FFFFH after TC.

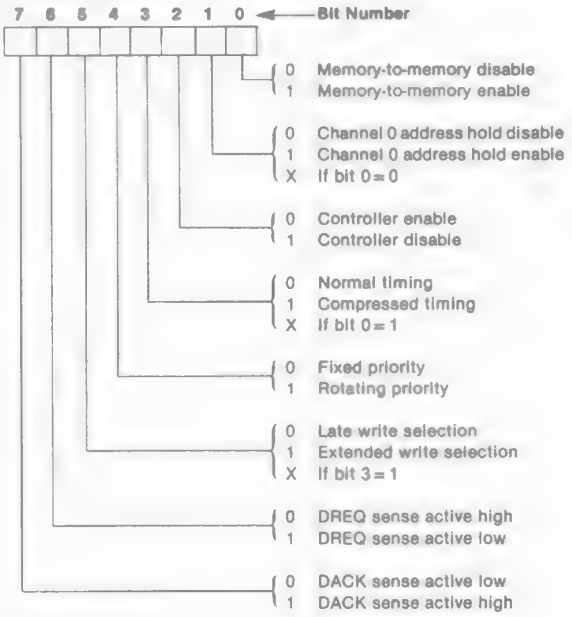
Base Address and Base Word Count Registers — Each channel has a pair of Base Address and Base Word Count registers. These 16-bit registers store the original value of their associated current registers. During Autoinitialize these values are used to restore the current registers to their original values. The base registers are written simultaneously with their corresponding current register in 8-bit bytes in the Program Condition by the microprocessor. These registers cannot be read by the microprocessor.

Command Register — This 8-bit register controls the operation of the 8237A. It is programmed by the microprocessor in the Program Condition and is cleared by Reset or a Master Clear instruction. The following table lists the function of the command bits. See Figure 6 for address coding.

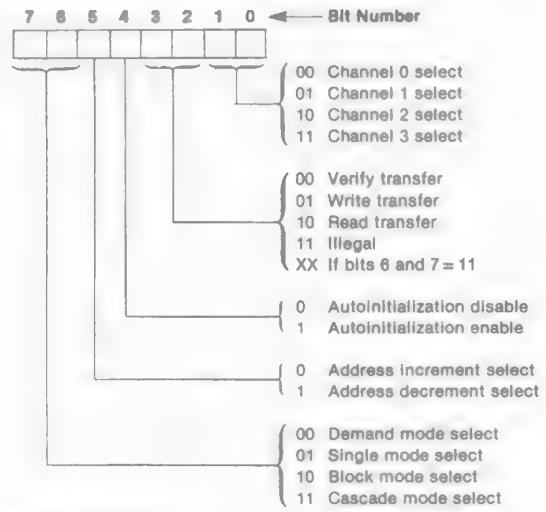
Mode Register — Each channel has a 6-bit Mode register associated with it. When the register is being written to by the microprocessor in the Program Condition, bits 0 and 1 determine which channel Mode register is to be written.

Request Register — The 8237A can respond to requests for DMA service which are initiated by software as well as by a DREQ. Each channel has a request bit associated with it in the 4-bit Request register. These are nonmaskable and subject to prioritization by the Priority Encoder network. Each register bit is set or reset separately under software control or is cleared upon generation of a TC or external $\overline{EOP}$. The entire register is cleared by a Reset. To set or reset a bit, the software loads the proper form of the data word. See Figure 5 for register address coding. In order to make a software request, the channel must be in Block Mode.

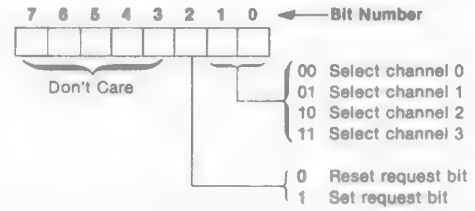
Command Register



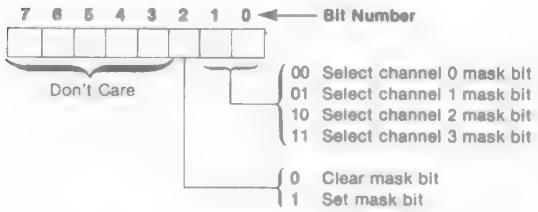
Mode Register



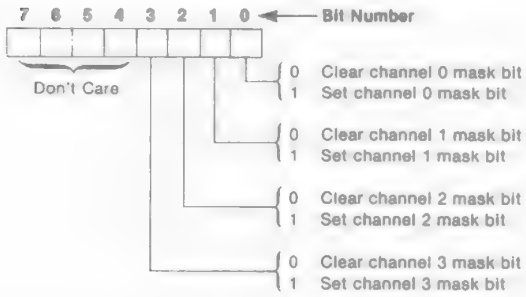
Request Register



Mask Register — Each channel has associated with it a mask bit which can be set to disable the incoming DREQ. Each mask bit is set when its associated channel produces an $\overline{EOP}$ if the channel is not programmed for Autoinitialize. Each bit of the 4-bit Mask register may also be set or cleared separately under software control. The entire register is also set by a Reset. This disables all DMA requests until a clear Mask register instruction allows them to occur. The instruction to separately set or clear the mask bits is similar in form to that used with the Request register. See Figure 5 for instruction addressing.



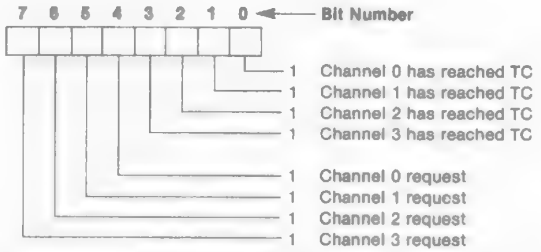
All four bits of the Mask register may also be written with a single command.



Register	Operation	Signals						
		$\overline{CS}$	$\overline{IOR}$	$\overline{IOW}$	A3	A2	A1	A0
Command	Write	0	1	0	1	0	0	0
Mode	Write	0	1	0	1	0	1	1
Request	Write	0	1	0	1	0	0	1
Mask	Set/Reset	0	1	0	1	0	1	0
Mask	Write	0	1	0	1	1	1	1
Temporary	Read	0	0	1	1	1	0	1
Status	Read	0	0	1	1	0	0	0

Figure 5. Definition of Register Codes

Status Register — The Status register is available to be read out of the 8237A by the microprocessor. It contains information about the status of the devices at this point. This information includes which channels have reached a terminal count and which channels have pending DMA requests. Bits 0-3 are set every time a TC is reached by that channel or an external $\overline{EOP}$ is applied. These bits are cleared upon Reset and on each Status Read. Bits 4-7 are set whenever their corresponding channel is requesting service.



Temporary Register — The Temporary register is used to hold data during memory-to-memory transfers. Following the completion of the transfers, the last word moved can be read by the microprocessor in the Program Condition. The Temporary register always contains the last byte transferred in the previous memory-to-memory operation, unless cleared by a Reset.

Software Commands — These are additional special software commands which can be executed in the Program Condition. They do not depend on any specific bit pattern on the data bus. The two software commands are:

Clear First/Last Flip-Flop: This command is executed prior to writing or reading new address or word count information to the 8237A. This initializes the flip-flop to a known state so that subsequent accesses to register contents by the microprocessor will address upper and lower bytes in the correct sequence.

Master Clear: This software instruction has the same effect as the hardware Reset. The Command, Status, Request, Temporary, and Internal First/Last Flip-Flop registers are cleared and the Mask register is set. The 8237A will enter the Idle cycle.

Clear Mask Register: This command clears the mask bits of all four channels, enabling them to accept DMA requests.

Figure 6 lists the address codes for the software commands:

Signals						Operation
A3	A2	A1	A0	$\overline{IOR}$	$\overline{IOW}$	
1	0	0	0	0	1	Read Status Register
1	0	0	0	1	0	Write Command Register
1	0	0	1	0	1	Illegal
1	0	0	1	1	0	Write Request Register
1	0	1	0	0	1	Illegal
1	0	1	0	1	0	Write Single Mask Register Bit
1	0	1	1	0	1	Illegal
1	0	1	1	1	0	Write Mode Register
1	1	0	0	0	1	Illegal
1	1	0	0	1	0	Clear Byte Pointer Flip/Flop
1	1	0	1	0	1	Read Temporary Register
1	1	0	1	1	0	Master Clear
1	1	1	0	0	1	Illegal
1	1	1	0	1	0	Clear Mask Register
1	1	1	1	0	1	Illegal
1	1	1	1	1	0	Write All Mask Register Bits

Figure 6. Software Command Codes

Channel	Register	Operation	Signals							Internal Flip-Flop	Data Bus DB0–DB7
			$\overline{CS}$	$\overline{IOR}$	$\overline{IOW}$	A3	A2	A1	A0		
0	Base and Current Address	Write	0	1	0	0	0	0	0	0	A0–A7
			0	1	0	0	0	0	0	1	A8–A15
	Current Address	Read	0	0	1	0	0	0	0	0	A0–A7
			0	0	1	0	0	0	0	1	A8–A15
	Base and Current Word Count	Write	0	1	0	0	0	0	1	0	W0–W7
			0	1	0	0	0	0	1	1	W8–W15
	Current Word Count	Read	0	0	1	0	0	0	1	0	W)0–W7
			0	0	1	0	0	0	1	1	W8–W15
1	Base and Current Address	Write	0	1	0	0	0	1	0	0	A0–A7
			0	1	0	0	0	1	0	1	A8–A15
	Current Address	Read	0	0	1	0	0	1	0	0	A0–A7
			0	0	1	0	0	1	0	1	A8–A15
	Base and Current Word Count	Write	0	1	0	0	0	1	1	0	W0–W7
			0	1	0	0	0	1	1	1	W8–W15
	Current Word Count	Read	0	0	1	0	0	1	1	0	W0-W7
			0	0	1	0	0	1	1	1	W8–W15
2	Base and Current Address	Write	0	1	0	0	1	0	0	0	A0–A7
			0	1	0	0	1	0	0	1	A8–A15
	Current Address	Read	0	0	1	0	1	0	0	0	A0–A7
			0	0	1	0	1	0	0	1	A8–A15
	Base and Current Word Count	Write	0	1	0	0	1	0	1	0	W0–W7
			0	1	0	0	1	0	1	1	W8–W15
	Current Word Count	Read	0	0	1	0	1	0	1	0	W)0–W7
			0	0	1	0	1	0	1	1	W8–W15
3	Base and Current Address	Write	0	1	0	0	1	1	0	0	A0–A7
			0	1	0	0	1	1	0	1	A8–A15
	Current Address	Read	0	0	1	0	1	1	0	0	A0–A7
			0	0	1	0	1	1	0	1	A8–A15
	Base and Current Word Count	Write	0	1	0	0	1	1	1	0	W0–W7
			0	1	0	0	1	1	1	1	W8–W15
	Current Word Count	Read	0	0	1	0	1	1	1	0	W)0–W7
			0	0	1	0	1	1	1	1	W8–W15

Figure 7. Word Count and Address Register Command Codes

PROGRAMMING

The 8237A will accept programming from the host processor any time that HLDA is inactive; this is true even if HRQ is active. The responsibility of the host is to assure that programming and HLDA are mutually exclusive. Note that a problem can occur if a DMA request occurs, on an unmasked channel while the 8237A is being programmed. For instance, the CPU may be starting to reprogram the two byte Address register of channel 1 when channel 1 receives a DMA request. If the 8237A is enabled (bit 2 in the command register is 0) and channel 1 is unmasked, a DMA service will occur after only one byte of the Address register has been reprogrammed. This can be avoided by disabling the controller (setting bit 2 in the command register) or masking the channel before programming any other registers. Once the programming is complete, the controller can be enabled/unmasked.

After power-up it is suggested that all internal locations, especially the Mode registers, be loaded with some valid value. This should be done even if some channels are unused.

APPLICATION INFORMATION

Figure 8 shows a convenient method for configuring a DMA system with the 8237A controller and an 8080A/8085AH microprocessor system. The multimode DMA controller issues a HRQ to the processor whenever there is at least one valid DMA request from a peripheral device. When the processor replies with a HLDA signal, the 8237A takes control of the address bus, the data bus and the control bus. The address for the first transfer operation comes out in two bytes — the least significant 8 bits on the eight address outputs and the most significant 8 bits on the data bus. The contents of the data bus are then latched into the 8282 8-bit latch to complete the full 16 bits of the address bus. The 8282 is a high speed, 8-bit, three-state latch in a 20-pin package. After the initial transfer takes place, the latch is updated only after a carry or borrow is generated in the least significant address byte. Four DMA channels are provided when one 8237A is used.

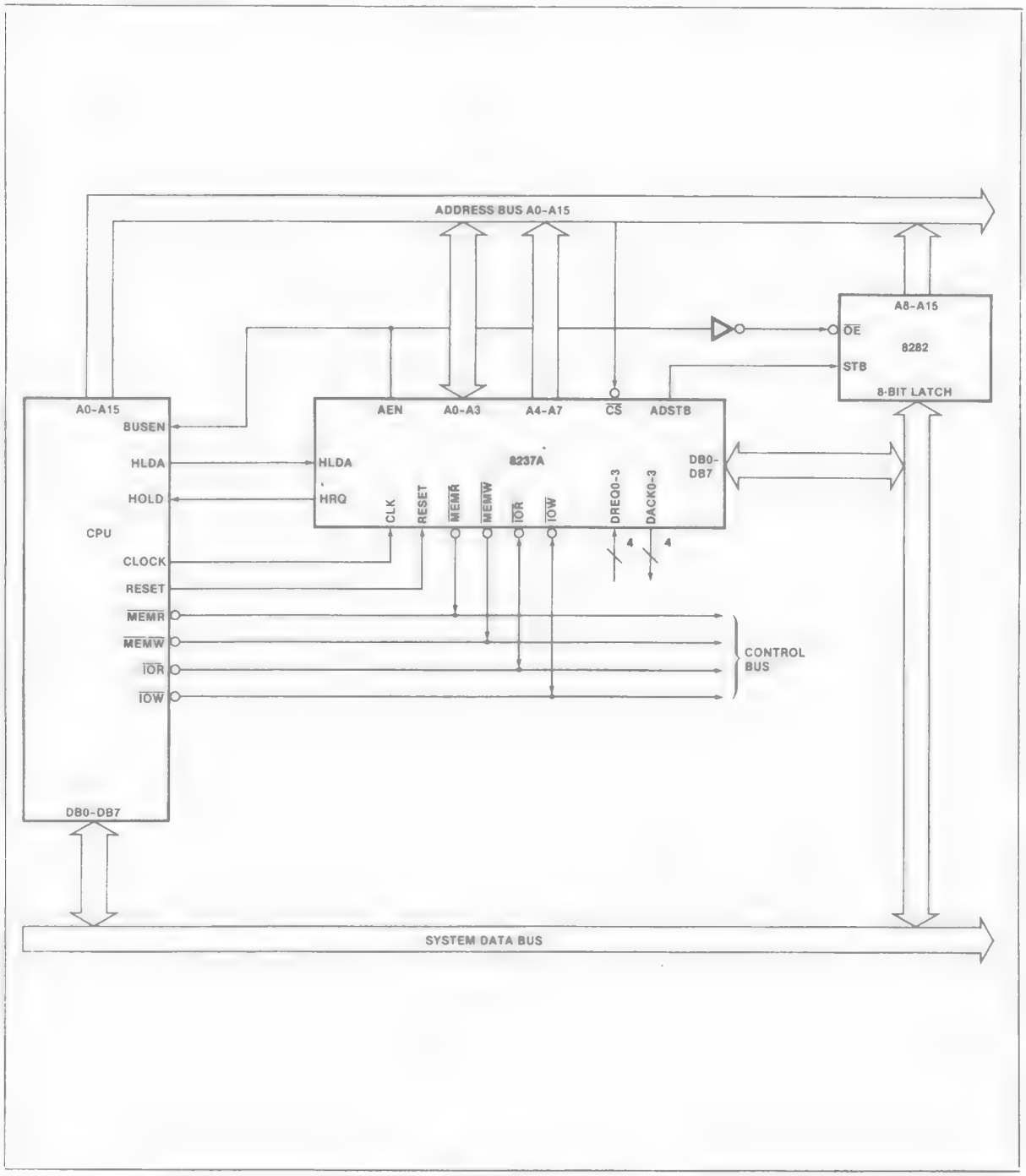


Figure 8. 8237A System Interface

AFN-00789D

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage on any Pin with
Respect to Ground ..... −0.5 to 7V
Power Dissipation ..... 1.5 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

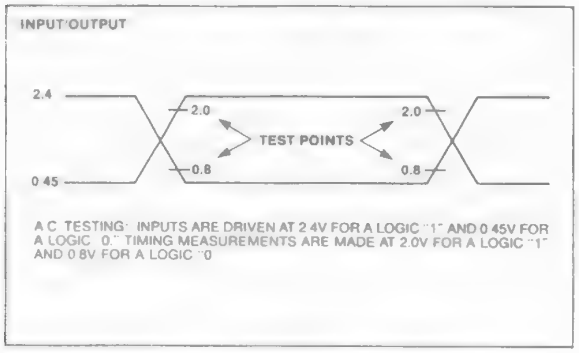
D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5.0V ±5%, GND = 0V)

Symbol	Parameter	Min.	Typ.(1)	Max.	Unit	Test Conditions
V_{OH}	Output HIGH Voltage	2.4			V	I_{OH} = −200 μA
		3.3			V	I_{OH} = −100 μA (HRQ Only)
V_{OL}	Output LOW Voltage			.45	V	I_{OL} = 2.0 mA (data bus) I_{OL} = 3.2 mA (other outputs)
V_{IH}	Input HIGH Voltage	2.0		V_{CC} + 0.5	V	
V_{IL}	Input LOW Voltage	−0.5		0.8	V	
I_{LI}	Input Load Current			±10	μA	0V ≤ V_{IN} ≤ V_{CC}
I_{LO}	Output Leakage Current			±10	μA	0.45V ≤ V_{OUT} ≤ V_{CC}
I_{CC}	V_{CC} Supply Current		65	130	mA	T_A = +25°C
			75	150	mA	T_A = 0°C
C_O	Output Capacitance		4	8	pF	fc = 1.0 MHz, Inputs = 0V
C_I	Input Capacitance		8	15	pF	
C_{IO}	I/O Capacitance		10	18	pF	

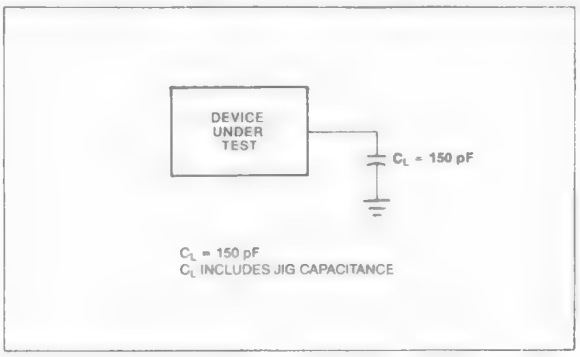
NOTES:

1. Typical values are for T_A = 25°C, nominal supply voltage and nominal processing parameters.
2. Input timing parameters assume transition times of 20 ns or less. Waveform measurement points for both input and output signals are 2.0V for HIGH and 0.8V for LOW, unless otherwise noted.
3. Output loading is 1 TTL gate plus 50 pF capacitance, unless otherwise noted.
4. The net $\overline{IOW}$ or $\overline{MEMW}$ Pulse width for normal write will be TCY-100 ns and for extended write will be 2TCY-100 ns. The net $\overline{IOR}$ or $\overline{MEMR}$ pulse width for normal read will be 2TCY-50 ns and for compressed read will be TCY-50 ns.
5. TDQ is specified for two different output HIGH levels. TDQ1 is measured at 2.0V. TDQ2 is measured at 3.3V. The value for TDQ2 assumes an external 3.3 kΩ pull-up resistor connected from HRQ to V_{CC}.
6. DREQ should be held active until DACK is returned.
7. DREQ and DACK signals may be active high or active low. Timing diagrams assume the active high mode.
8. Output loading on the data bus is 1 TTL gate plus 100 pF capacitance.
9. Successive read and/or write operations by the external processor to program or examine the controller must be timed to allow at least 600 ns for the 8237A, at least 500 ns for the 8237A-4 and at least 400 ns for the 8237A-5, as recovery time between active read or write pulses.
10. Parameters are listed in alphabetical order.
11. Pin 5 is an input that should always be at a logic high level. An internal pull-up resistor will establish a logic high when the pin is left floating. Alternatively, pin 5 may be tied to V_{CC}.

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING LOAD CIRCUIT



A.C. CHARACTERISTICS—DMA (MASTER) MODE ($T_A = 0°C$ to $70°C$, $V_{CC} = +5V \pm 5\%$, GND = 0V)

Symbol	Parameter	8237A		8237A-4		8237A-5		Unit
		Min.	Max.	Min.	Max.	Min.	Max.	
TAEL	AEN HIGH from CLK LOW (S1) Delay Time		300		225		200	ns
TAET	AEN LOW from CLK HIGH (S1) Delay Time		200		150		130	ns
TAFAB	ADR Active to Float Delay from CLK HIGH		150		120		90	ns
TAFC	$\overline{READ}$ or $\overline{WRITE}$ Float from CLK HIGH		150		120		120	ns
TAFDB	DB Active to Float Delay from CLK HIGH		250		190		170	ns
TAHR	ADR from $\overline{READ}$ HIGH Hold Time	TCY–100		TCY–100		TCY–100		ns
TAHS	DB from ADSTB LOW Hold Time	50		40		30		ns
TAHW	ADR from $\overline{WRITE}$ HIGH Hold Time	TCY–50		TCY–50		TCY–50		ns
TAK	DACK Valid from CLK LOW Delay Time (Note 7)		250		220		170	ns
	$\overline{EOP}$ HIGH from CLK HIGH Delay Time		250		190		170	ns
	$\overline{EOP}$ LOW to CLK HIGH Delay Time		250		190		100	ns
TASM	ADR Stable from CLK HIGH		250		190		170	ns
TASS	DB to ADSTB LOW Setup Time	100		100		100		ns
TCH	Clock High Time (Transitions ≤ 10 ns)	120		100		80		ns
TCL	Clock LOW Time (Transitions ≤ 10 ns)	150		110		68		ns
TCY	CLK Cycle Time	320		250		200		ns
TDCL	CLK HIGH to $\overline{READ}$ or $\overline{WRITE}$ LOW Delay (Note 4)		270		200		190	ns
TDCTR	$\overline{READ}$ HIGH from CLK HIGH (S4) Delay Time (Note 4)		270		210		190	ns
TDCTW	$\overline{WRITE}$ HIGH from CLK HIGH (S4) Delay Time (Note 4)		200		150		130	ns
TDQ1	HRQ Valid from CLK HIGH Delay Time (Note 5)		160		120		120	ns
TDQ2			250		190		120	ns
TEPS	$\overline{EOP}$ LOW from CLK LOW Setup Time	60		45		40		ns
TEPW	$\overline{EOP}$ Pulse Width	300		225		220		ns
TFAAB	ADR Float to Active Delay from CLK HIGH		250		190		170	ns
TFAC	$\overline{READ}$ or $\overline{WRITE}$ Active from CLK HIGH		200		150		150	ns
TFADB	DB Float to Active Delay from CLK HIGH		300		225		200	ns
THS	HLDA Valid to CLK HIGH Setup Time	100		75		75		ns
TIDH	Input Data from $\overline{MEMR}$ HIGH Hold Time	0		0		0		ns
TIDS	Input Data to $\overline{MEMR}$ HIGH Setup Time	250		190		170		ns
TODH	Output Data from $\overline{MEMW}$ HIGH Hold Time	20		20		10		ns
TODV	Output Data Valid to $\overline{MEMW}$ HIGH	200		125		125		ns
TQS	DREQ to CLK LOW (SI, S4) Setup Time (Note 7)	0		0		0		ns
TRH	CLK to READY LOW Hold Time	20		20		20		ns
TRS	READY to CLK LOW Setup Time	100		60		60		ns
TSTL	ADSTB HIGH from CLK HIGH Delay Time		200		150		130	ns
TSTT	ADSTB LOW from CLK HIGH Delay Time		140		110		90	ns

A.C. CHARACTERISTICS—PERIPHERAL (SLAVE) MODE (T_A = 0°C to 70°C, V_{CC} = 5.0V ±5%, GND = 0V)

Symbol	Parameter	8237A		8237A-4		8237A-5		Unit
		Min.	Max.	Min.	Max.	Min.	Max.	
TAR	ADR Valid or $\overline{CS}$ LOW to $\overline{READ}$ LOW	50		50		50		ns
TAW	ADR Valid to $\overline{WRITE}$ HIGH Setup Time	200		150		150		ns
TCW	CS LOW to $\overline{WRITE}$ HIGH Setup Time	200		150		150		ns
TDW	Data Valid to $\overline{WRITE}$ HIGH Setup Time	200		150		150		ns
TRA	ADR or CS Hold from $\overline{READ}$ HIGH	0		0		0		ns
TRDE	Data Access from $\overline{READ}$ LOW (Note 8)		200		200		140	ns
TRDF	DB Float Delay from $\overline{READ}$ HIGH	20	100	20	100	0	70	ns
TRSTD	Power Supply HIGH to RESET LOW Setup Time	500		500		500		ns
TRSTS	RESET to First $\overline{IOWR}$	2TCY		2TCY		2TCY		ns
TRSTW	RESET Pulse Width	300		300		300		ns
TRW	$\overline{READ}$ Width	300		250		200		ns
TWA	ADR from $\overline{WRITE}$ HIGH Hold Time	20		20		20		ns
TWC	CS HIGH from $\overline{WRITE}$ HIGH Hold Time	20		20		20		ns
TWD	Data from $\overline{WRITE}$ HIGH Hold Time	30		30		30		ns
TWWS	Write Width	200		200		160		ns

WAVEFORMS

SLAVE MODE WRITE TIMING

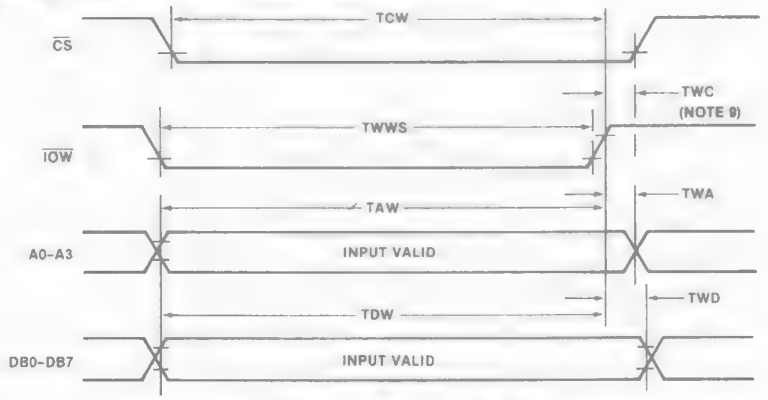


Figure 9. Slave Mode Write

SLAVE MODE READ TIMING

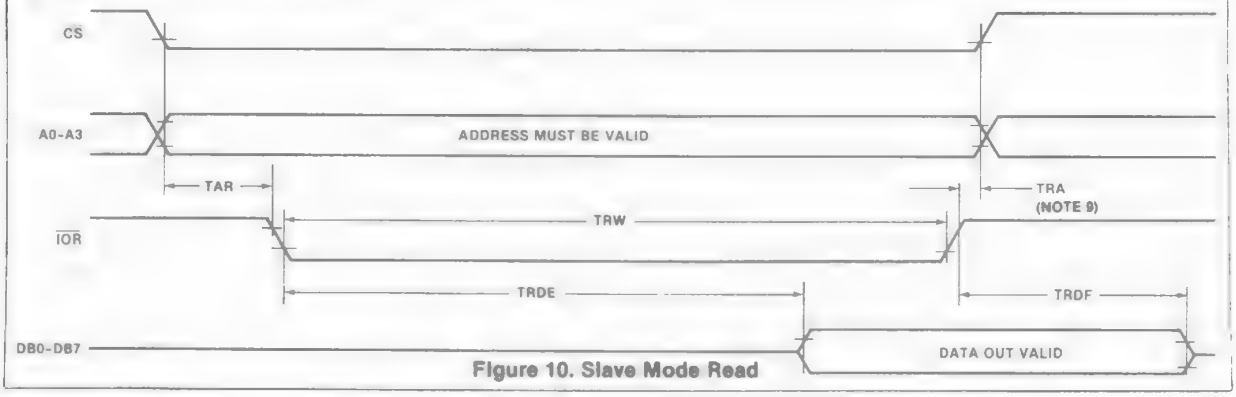


Figure 10. Slave Mode Read

AFN-00789D

WAVEFORMS (Continued)

DMA TRANSFER TIMING

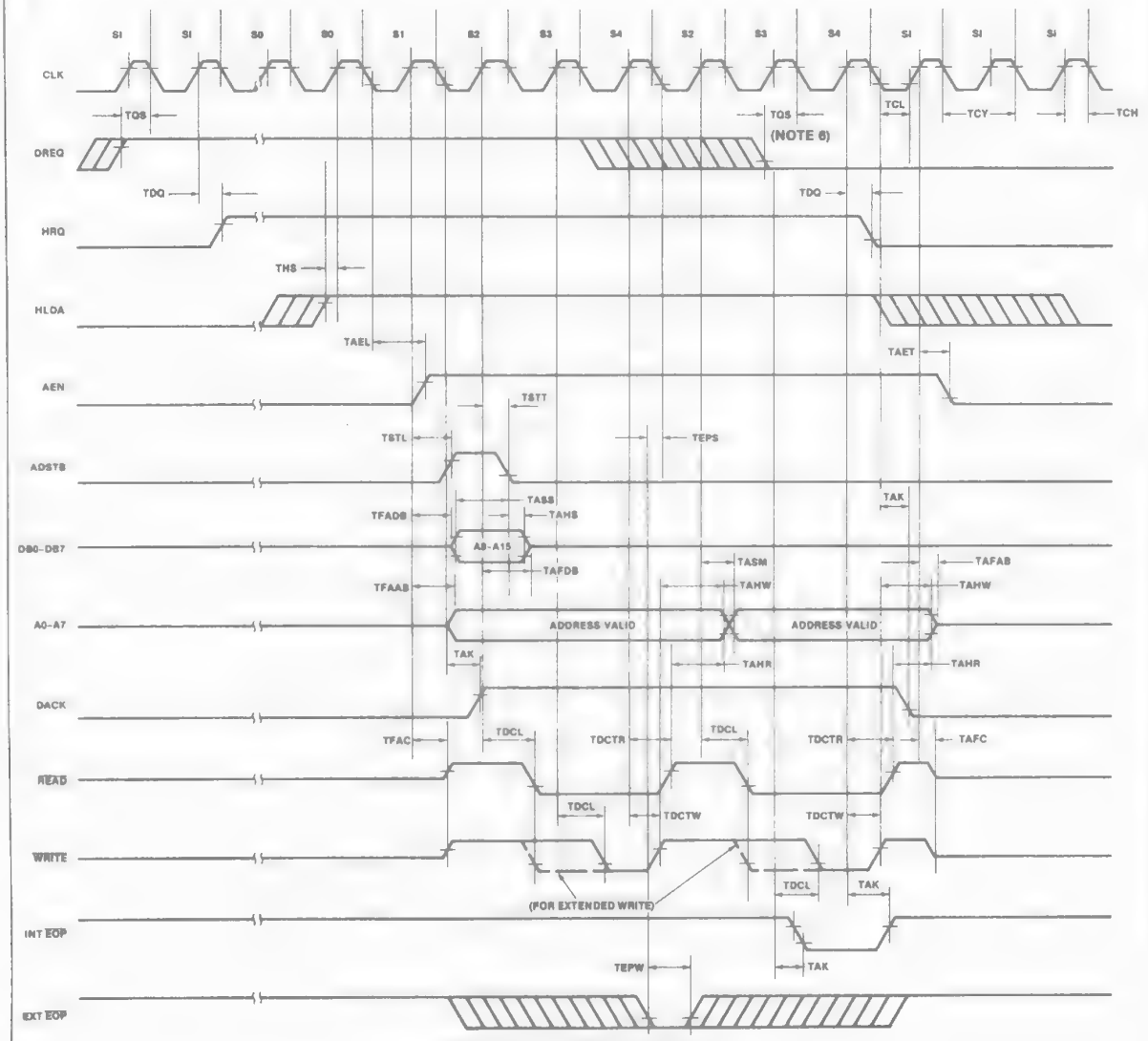


Figure 11. DMA Transfer

WAVEFORMS (Continued)

MEMORY-TO-MEMORY TRANSFER TIMING

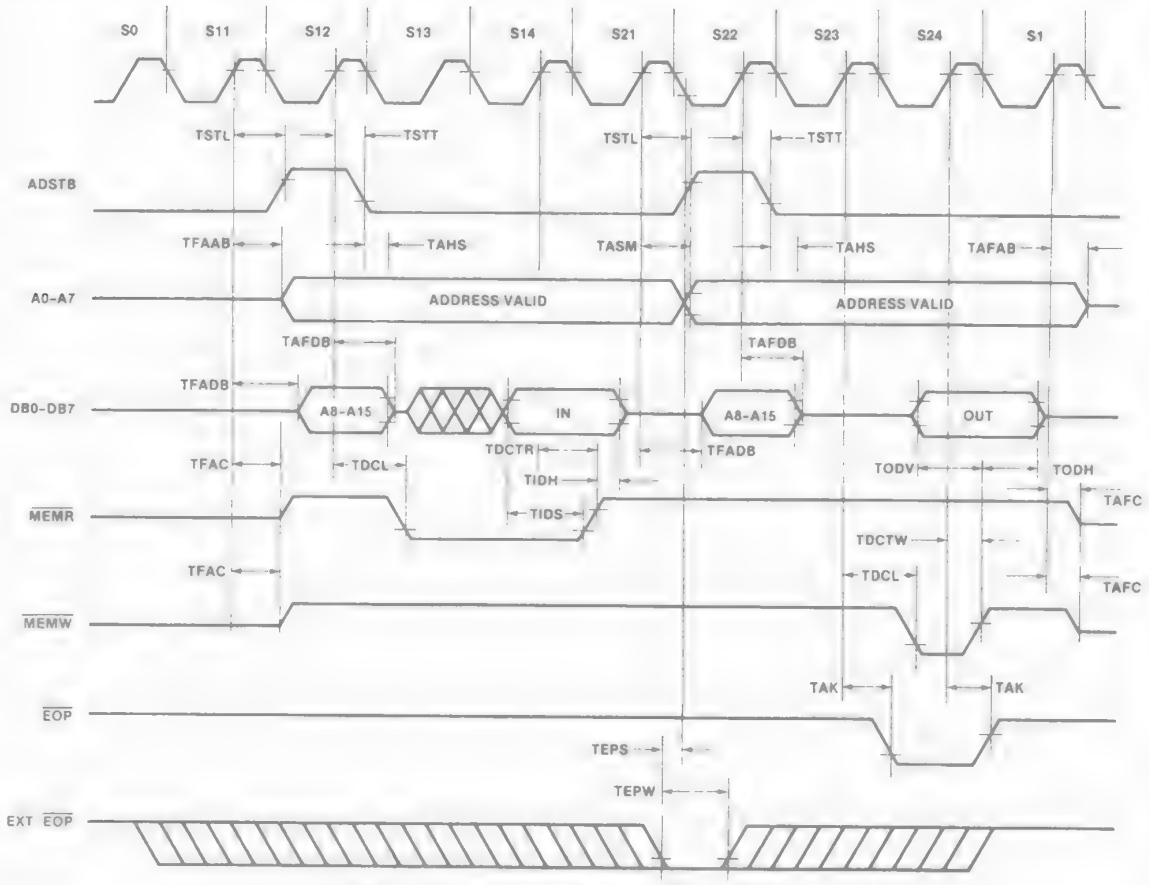


Figure 12. Memory-to-Memory Transfer

READY TIMING

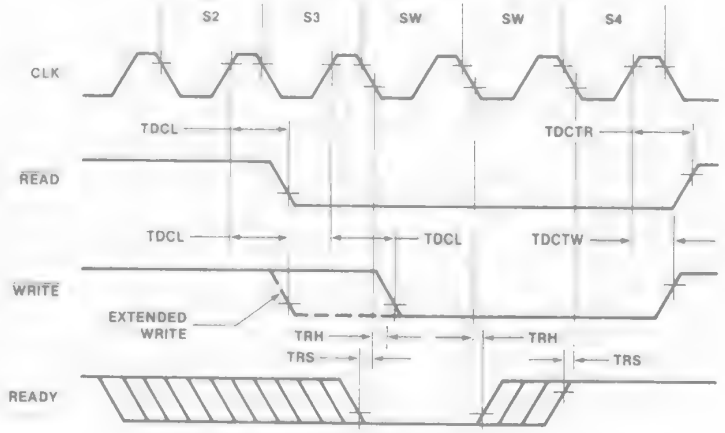


Figure 13. Ready

WAVEFORMS (Continued)

COMPRESSED TRANSFER TIMING

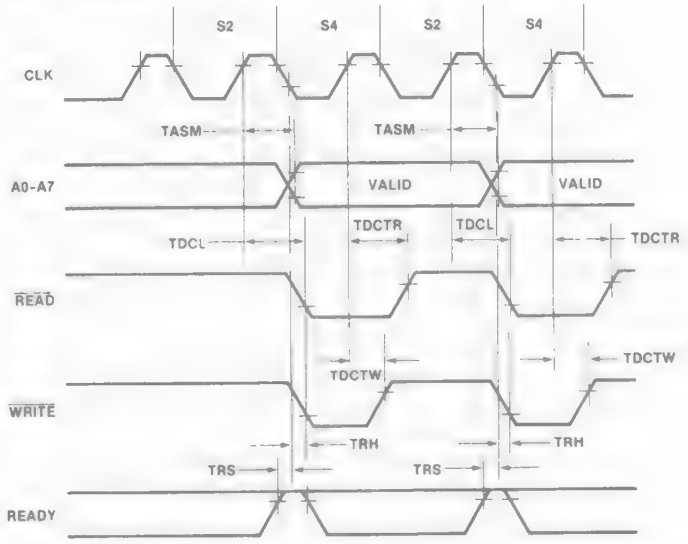


Figure 14. Compressed Transfer

RESET TIMING

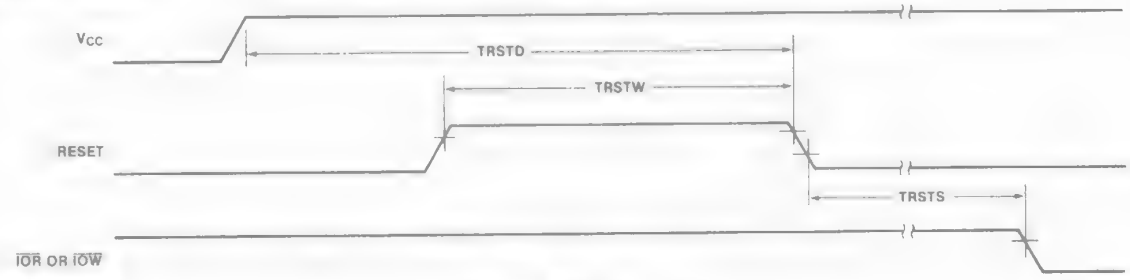


Figure 15. Reset

8257/8257-5
PROGRAMMABLE DMA CONTROLLER

- **MCS-85® Compatible 8257-5**
- **4-Channel DMA Controller**
- **Priority DMA Request Logic**
- **Channel Inhibit Logic**
- **Terminal Count and Modulo 128 Outputs**
- **Single TTL Clock**
- **Single +5V Supply**
- **Auto Load Mode**
- **Available In EXPRESS**
  - Standard Temperature Range

The Intel® 8257 is a 4-channel direct memory access (DMA) controller. It is specifically designed to simplify the transfer of data at high speeds for the Intel® microcomputer systems. Its primary function is to generate, upon a peripheral request, a sequential memory address which will allow the peripheral to read or write data directly to or from memory. Acquisition of the system bus in accomplished via the CPU's hold function. The 8257 has priority logic that resolves the peripherals requests and issues a composite hold request to the CPU. It maintains the DMA cycle count for each channel and outputs a control signal to notify the peripheral that the programmed number of DMA cycles is complete. Other output control signals simplify sectored data transfers. The 8257 represents a significant savings in component count for DMA-based microcomputer systems and greatly simplifies the transfer of data at high speed between peripherals and memories.

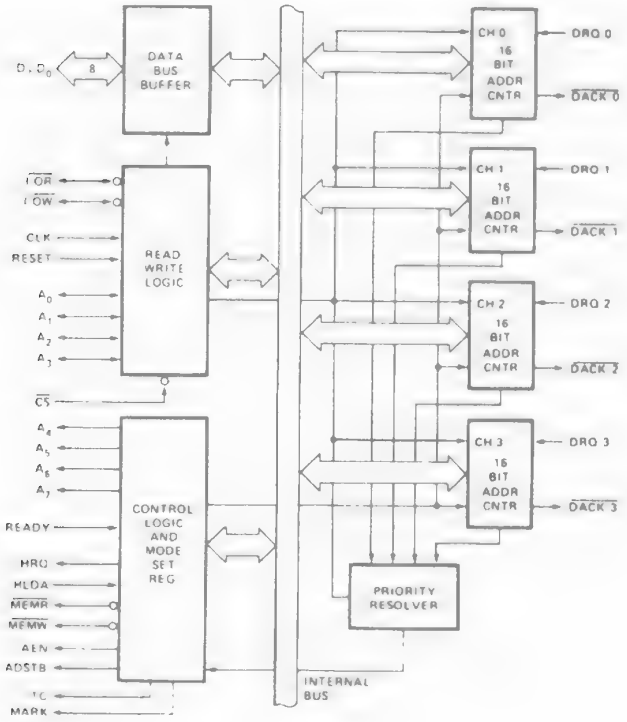


Figure 1. Block Diagram

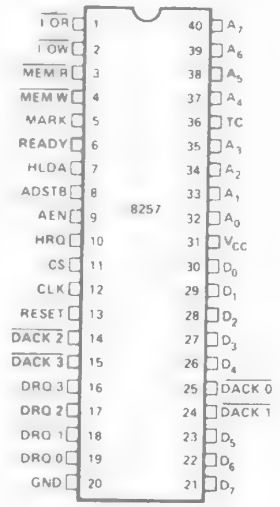


Figure 2. Pin Configuration

FUNCTIONAL DESCRIPTION

General

The 8257 is a programmable, Direct Memory Access (DMA) device which, when coupled with a single Intel® 8212 I/O port device, provides a complete four-channel DMA controller for use in Intel® microcomputer systems. After being initialized by software, the 8257 can transfer a block of data, containing up to 16,384 bytes, between memory and a peripheral device directly, without further intervention required of the CPU. Upon receiving a DMA transfer request from an enabled peripheral, the 8257:

1. Acquires control of the system bus.
2. Acknowledges that requesting peripheral which is connected to the highest priority channel.
3. Outputs the least significant eight bits of the memory address onto system address lines A_0-A_7, outputs the most significant eight bits of the memory address to the 8212 I/O port via the data bus (the 8212 places these address bits on lines A_8-A_{15}), and
4. Generates the appropriate memory and I/O read/write control signals that cause the peripheral to receive or deposit a data byte directly from or to the addressed location in memory.

The 8257 will retain control of the system bus and repeat the transfer sequence, as long as a peripheral maintains its DMA request. Thus, the 8257 can transfer a block of data to/from a high speed peripheral (e.g., a sector of data on a floppy disk) in a single "burst". When the specified number of data bytes have been transferred, the 8257 activates its Terminal Count (TC) output, informing the CPU that the operation is complete.

The 8257 offers three different modes of operation: (1) DMA read, which causes data to be transferred from memory to a peripheral; (2) DMA write, which causes data to be transferred from a peripheral to memory; and (3) DMA verify, which does not actually involve the transfer of data. When an 8257 channel is in the DMA verify mode, it will respond the same as described for transfer operations, except that no memory or I/O read/write control signals will be generated, thus preventing the transfer of data. The 8257, however, will gain control of the system bus and will acknowledge the peripheral's DMA request for each DMA cycle. The peripheral can use these acknowledge signals to enable an internal access of each byte of a data block in order to execute some verification procedure, such as the accumulation of a CRC (Cyclic Redundancy Code) checkword. For example, a block of DMA verify cycles might follow a block of DMA read cycles (memory to peripheral) to allow the peripheral to verify its newly acquired data.

Block Diagram Description

1. DMA Channels

The 8257 provides four separate DMA channels (labeled CH-0 to CH-3). Each channel includes two sixteen-bit registers: (1) a DMA address register, and (2) a terminal count register. Both registers must be initialized before a channel is enabled. The DMA address register is loaded with the address of the first memory location to be accessed. The value loaded into the low-order 14-bits of the terminal count register specifies the number of DMA cycles minus one before the Terminal Count (TC) output is activated. For instance, a terminal count of 0 would cause the TC output to be active in the first DMA cycle for that channel. In general, if N = the number of desired DMA cycles, load the value N-1 into the low-order 14-bits of the terminal count register. The most significant two bits of the terminal count register specify the type of DMA operation for that channel.

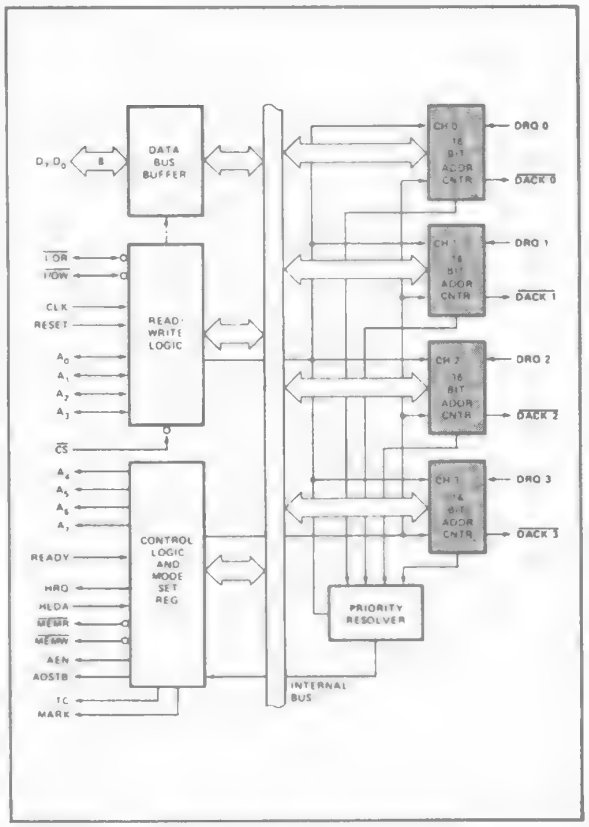


Figure 3. 8257 Block Diagram Showing DMA Channels

These two bits are not modified during a DMA cycle, but can be changed between DMA blocks.

Each channel accepts a DMA Request (DRQn) input and provides a DMA Acknowledge (DACKn) output.

(DRQ 0–DRQ 3)

DMA Request: These are individual asynchronous channel request inputs used by the peripherals to obtain a DMA cycle. If not in the rotating priority mode then DRQ 0 has the highest priority and DRQ 3 has the lowest. A request can be generated by raising the request line and holding it high until DMA acknowledge. For multiple DMA cycles (Burst Mode) the request line is held high until the DMA acknowledge of the last cycle arrives.

($\overline{\text{DACK 0 - DACK 3}}$)

DMA Acknowledge: An active low level on the acknowledge output informs the peripheral connected to that channel that it has been selected for a DMA cycle. The $\overline{\text{DACK}}$ output acts as a "chip select" for the peripheral device requesting service. This line goes active (low) and inactive (high) once for each byte transferred even if a burst of data is being transferred.

2. Data Bus Buffer

This three-state, bi-directional, eight bit buffer interfaces the 8257 to the system data bus.

(D_0–D_7)

Data Bus Lines: These are bi-directional three-state lines When the 8257 is being programmed by the CPU, eight-bits of data for a DMA address register, a terminal count register or the Mode Set register are received on the data bus. When the CPU reads a DMA address register, a terminal count register or the Status register, the data is sent to the CPU over the data bus. During DMA cycles (when the 8257 is the bus master), the 8257 will output the most significant eight-bits of the memory address (from one of the DMA address registers) to the 8212 latch via the data bus. These address bits will be transferred at the beginning of the DMA cycle; the bus will then be released to handle the memory data transfer during the balance of the DMA cycle.

BIT 15	BIT 14	TYPE OF DMA OPERATION
0	0	Verify DMA Cycle
0	1	Write DMA Cycle
1	0	Read DMA Cycle
1	1	(Illegal)

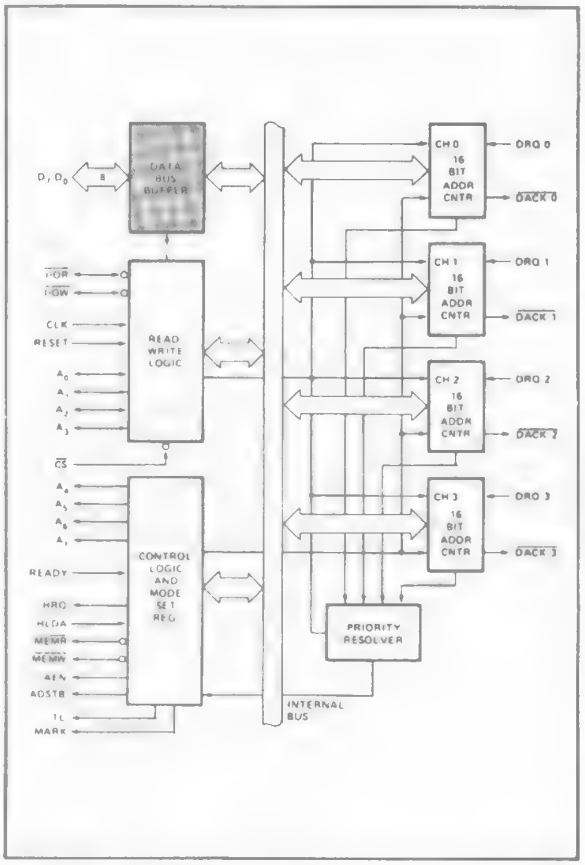


Figure 4. 8257 Block Diagram Showing Data Bus Buffer

3. Read/Write Logic

When the CPU is programming or reading one of the 8257's registers (i.e., when the 8257 is a "slave" device on the system bus), the Read/Write Logic accepts the I/O Read ($\overline{I/OR}$) or I/O Write ($\overline{I/OW}$) signal, decodes the least significant four address bits, (A_0-A_3), and either writes the contents of the data bus into the addressed register (if $\overline{I/OW}$ is true) or places the contents of the addressed register onto the data bus (if $\overline{I/OR}$ is true).

During DMA cycles (i.e., when the 8257 is the bus "master"), the Read/Write Logic generates the I/O read and memory write (DMA write cycle) or I/O Write and memory read (DMA read cycle) signals which control the data link with the peripheral that has been granted the DMA cycle.

Note that during DMA transfers Non-DMA I/O devices should be de-selected (disabled) using "AEN" signal to inhibit I/O device decoding of the memory address as an erroneous device address.

($\overline{I/OR}$)

I/O Read: An active-low, bi-directional three-state line. In the "slave" mode, it is an input which allows the 8-bit status register or the upper/lower byte of a 16-bit DMA address register or terminal count register to be read. In the "master" mode, $\overline{I/OR}$ is a control output which is used to access data from a peripheral during the DMA write cycle.

($\overline{I/OW}$)

I/O Write: An active-low, bi-directional three-state line. In the "slave" mode, it is an input which allows the contents of the data bus to be loaded into the 8-bit mode set register or the upper/lower byte of a 16-bit DMA address register or terminal count register. In the "master" mode, $\overline{I/OW}$ is a control output which allows data to be output to a peripheral during a DMA read cycle.

(CLK)

Clock Input: Generally from an Intel® 8224 Clock Generator device. (ϕ2 TTL) or Intel® 8085A CLK output.

(RESET)

Reset: An asynchronous input (generally from an 8224 or 8085 device) which disables all DMA channels by clearing the mode register and 3-states all control lines.

(A_0-A_3)

Address Lines: These least significant four address lines are bi-directional. In the "slave" mode they are inputs which select one of the registers to be read or programmed. In the "master" mode, they are outputs which constitute the least significant four bits of the 16-bit memory address generated by the 8257.

($\overline{CS}$)

Chip Select: An active-low input which enables the I/O Read or I/O Write input when the 8257 is being read or programmed in the "slave" mode. In the "master" mode, $\overline{CS}$ is automatically disabled to prevent the chip from selecting itself while performing the DMA function.

4. Control Logic

This block controls the sequence of operations during all DMA cycles by generating the appropriate control signals and the 16-bit address that specifies the memory location to be accessed.

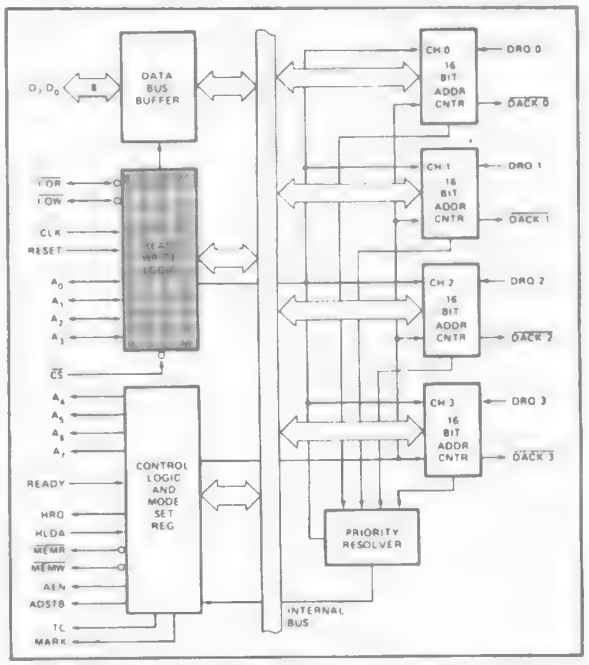


Figure 5. 8257 Block Diagram Showing Read/Write Logic Function

(A_4-A_7)

Address Lines: These four address lines are three-state outputs which constitute bits 4 through 7 of the 16-bit memory address generated by the 8257 during all DMA cycles

(READY)

Ready: This asynchronous input is used to elongate the memory read and write cycles in the 8257 with wait states if the selected memory requires longer cycles. READY must conform to specified setup and hold times.

(HRQ)

Hold Request: This output requests control of the system bus. In systems with only one 8257, HRQ will normally be applied to the HOLD input on the CPU. HRQ must conform to specified setup and hold times.

(HLDA)

Hold Acknowledge: This input from the CPU indicates that the 8257 has acquired control of the system bus.

($\overline{MEMR}$)

Memory Read: This active-low three-state output is used to read data from the addressed memory location during DMA Read cycles.

($\overline{MEMW}$)

Memory Write: This active-low three-state output is used to write data into the addressed memory location during DMA Write cycles.

(ADSTB)

Address Strobe: This output strobes the most significant byte of the memory address into the 8212 device from the data bus.

(AEN)

Address Enable: This output is used to disable (float) the System Data Bus and the System Control Bus. It may also be used to disable (float) the System Address Bus by use of an enable on the Address Bus drivers in systems to inhibit non-DMA devices from responding during DMA cycles. It may be further used to isolate the 8257 data bus from the System Data Bus to facilitate the transfer of the 8 most significant DMA address bits over the 8257 data I/O pins without subjecting the System Data Bus to any timing constraints for the transfer. When the 8257 is used in an I/O device structure (as opposed to memory mapped), this AEN output should be used to disable the selection of an I/O device when the DMA address is on the address bus. The I/O device selection should be determined by the DMA acknowledge outputs for the 4 channels

(TC)

Terminal Count: This output notifies the currently selected peripheral that the present DMA cycle should be the last cycle for this data block. If the TC STOP bit in the Mode Set register is set, the selected channel will be automatically disabled at the end of that DMA cycle. TC is activated when the 14-bit value in the selected channel's terminal count register equals zero. Recall that the low-order 14-bits of the terminal count register should be loaded with the values (n-1), where n = the desired number of the DMA cycles.

(MARK)

Modulo 128 Mark: This output notifies the selected peripheral that the current DMA cycle is the 128th cycle since the previous MARK output. MARK always occurs at 128 (and all multiples of 128) cycles from the end of the data block. Only if the total number of DMA cycles (n) is evenly divisable by 128 (and the terminal count register was loaded with n-1), will MARK occur at 128 (and each succeeding multiple of 128) cycles from the beginning of the data block.

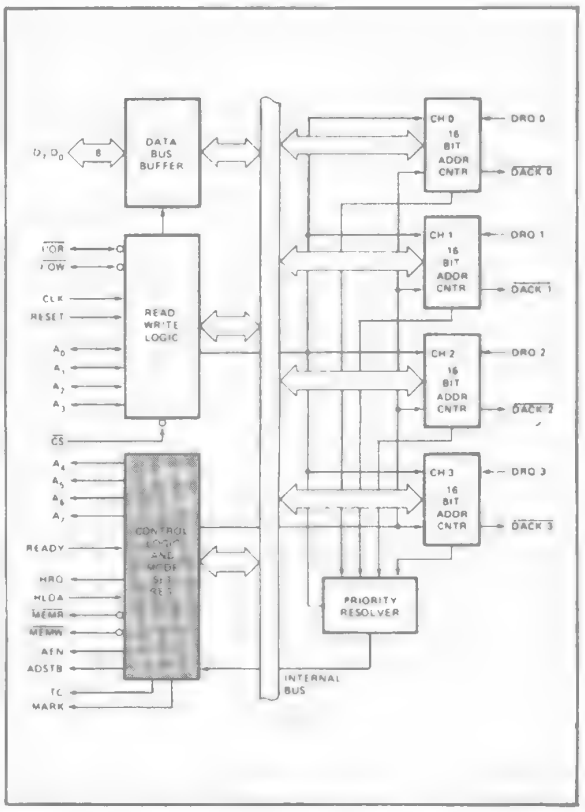
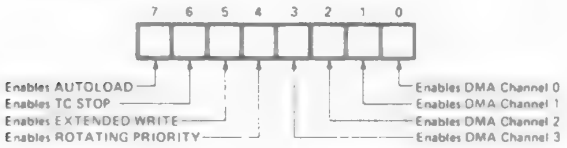


Figure 6. 8257 Block Diagram Showing Control Logic and Mode Set Register

5. Mode Set Register

When set, the various bits in the Mode Set register enable each of the four DMA channels, and allow four different options for the 8257:

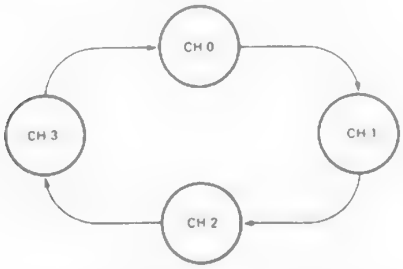


The Mode Set register is normally programmed by the CPU after the DMA address register(s) and terminal count register(s) are initialized. The Mode Set Register is cleared by the RESET input, thus disabling all options, inhibiting all channels, and preventing bus conflicts on power-up. A channel should not be left enabled unless its DMA address and terminal count registers contain valid values; otherwise, an inadvertent DMA request (DRQn) from a peripheral could initiate a DMA cycle that would destroy memory data.

The various options which can be enabled by bits in the Mode Set register are explained below:

Rotating Priority Bit 4

In the Rotating Priority Mode, the priority of the channels has a circular sequence. After each DMA cycle, the priority of each channel changes. The channel which had just been serviced will have the lowest priority.



If the ROTATING PRIORITY bit is not set (set to a zero), each DMA channel has a fixed priority. In the fixed priority mode, Channel 0 has the highest priority and Channel 3 has the lowest priority. If the ROTATING PRIORITY bit is set to a one, the priority of each channel changes after each DMA cycle (not each DMA request). Each channel moves up to the next highest priority assignment, while the channel which has just been serviced moves to the lowest priority assignment:

	CHANNEL→ JUST SERVICED	CH-0	CH-1	CH-2	CH-3
Priority → Assignments	Highest	CH-1	CH-2	CH-3	CH-0
	↑	CH-2	CH-3	CH-0	CH-1
	↓	CH-3	CH-0	CH-1	CH-2
	Lowest	CH-0	CH-1	CH-2	CH-3

Note that rotating priority will prevent any one channel from monopolizing the DMA mode; consecutive DMA cycles will service different channels if more than one channel is enabled and requesting service. There is no overhead penalty associated with this mode of operation. All DMA operations began with Channel 0 initially assigned to the highest priority for the first DMA cycle.

Extended Write Bit 5

If the EXTENDED WRITE bit is set, the duration of both the $\overline{MEMW}$ and $\overline{I/OW}$ signals is extended by activating them earlier in the DMA cycle. Data transfers within microcomputer systems proceed asynchronously to allow use of various types of memory and I/O devices with different access times. If a device cannot be accessed within a specific amount of time it returns a "not ready" indication to the 8257 that causes the 8257 to insert one or more wait states in its internal sequencing. Some devices are fast enough to be accessed without the use of wait states, but if they generate their READY response with the leading edge of the $\overline{I/OW}$ or $\overline{MEMW}$ signal (which generally occurs late in the transfer sequence), they would normally cause the 8257 to enter a wait state because it does not receive READY in time. For systems with these types of devices, the Extended Write option provides alternative timing for the I/O and memory write signals which allows the devices to return an early READY and prevents the unnecessary occurrence of wait states in the 8257, thus increasing system throughput

TC Stop Bit 6

If the TC STOP bit is set, a channel is disabled (i.e., its enable bit is reset) after the Terminal Count (TC) output goes true, thus automatically preventing further DMA operation on that channel. The enable bit for that channel must be re-programmed to continue or begin another DMA operation. If the TC STOP bit is not set, the occurrence of the TC output has no effect on the channel enable bits. In this case, it is generally the responsibility of the peripheral to cease DMA requests in order to terminate a DMA operation.

Auto Load Bit 7

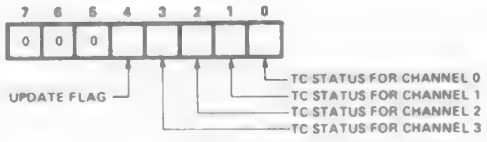
The Auto Load mode permits Channel 2 to be used for repeat block or block chaining operations, without immediate software intervention between blocks. Channel 2 registers are initialized as usual for the first data block; Channel 3 registers, however, are used to store the block re-initialization parameters (DMA starting address, terminal count and DMA transfer mode). After the first block of DMA cycles is executed by Channel 2 (i.e., after the TC output goes true), the parameters stored in the Channel 3 registers are transferred to Channel 2 during an "update" cycle. Note that the TC STOP feature, described above, has no effect on Channel 2 when the Auto Load bit is set.

If the Auto Load bit is set, the initial parameters for Channel 2 are automatically duplicated in the Channel 3 registers when Channel 2 is programmed. This permits repeat block operations to be set up with the programming of a single channel. Repeat block operations can be used in applications such as CRT refreshing. Channels 2 and 3 can still be loaded with separate values if Channel 2 is loaded before loading Channel 3. Note that in the Auto Load mode, Channel 3 is still available to the user if the Channel 3 enable bit is set, but use of this channel will change the values to be auto loaded into Channel 2 at update time. All that is necessary to use the Auto Load feature for chaining operations is to reload Channel 3 registers at the conclusion of each update cycle with the new parameters for the next data block transfer.

Each time that the 8257 enters an update cycle, the update flag in the status register is set and parameters in Channel 3 are transferred to Channel 2, non-destructively for Channel 3. The actual re-initialization of Channel 2 occurs at the beginning of the next channel 2 DMA cycle after the TC cycle. This will be the first DMA cycle of the new data block for Channel 2. The update flag is cleared at the conclusion of this DMA cycle. For chaining operations, the update flag in the status register can be monitored by the CPU to determine when the re-initialization process has been completed so that the next block parameters can be safely loaded into Channel 3.

6. Status Register

The eight-bit status register indicates which channels have reached a terminal count condition and includes the update flag described previously.



The TC status bits are set when the Terminal Count (TC) output is activated for that channel. These bits remain set until the status register is read or the 8257 is reset. The UPDATE FLAG, however, is not affected by a status register read operation. The UPDATE FLAG can be cleared by resetting the 8257, by changing to the non-auto load mode (i.e., by resetting the AUTO LOAD bit in the Mode Set register) or it can be left to clear itself at the completion of the update cycle. The purpose of the UPDATE FLAG is to prevent the CPU from inadvertently skipping a data block by overwriting a starting address or terminal count in the Channel 3 registers before those parameters are properly auto-loaded into Channel 2.

The user is cautioned against reading the TC status register and using this information to reenable channels that have not completed operation. Unless the DMA channels are inhibited a channel could reach terminal count (TC) between the status read and the mode write. DMA can be inhibited by a hardware gate on the HRQ line or by disabling channels with a mode word before reading the TC status.

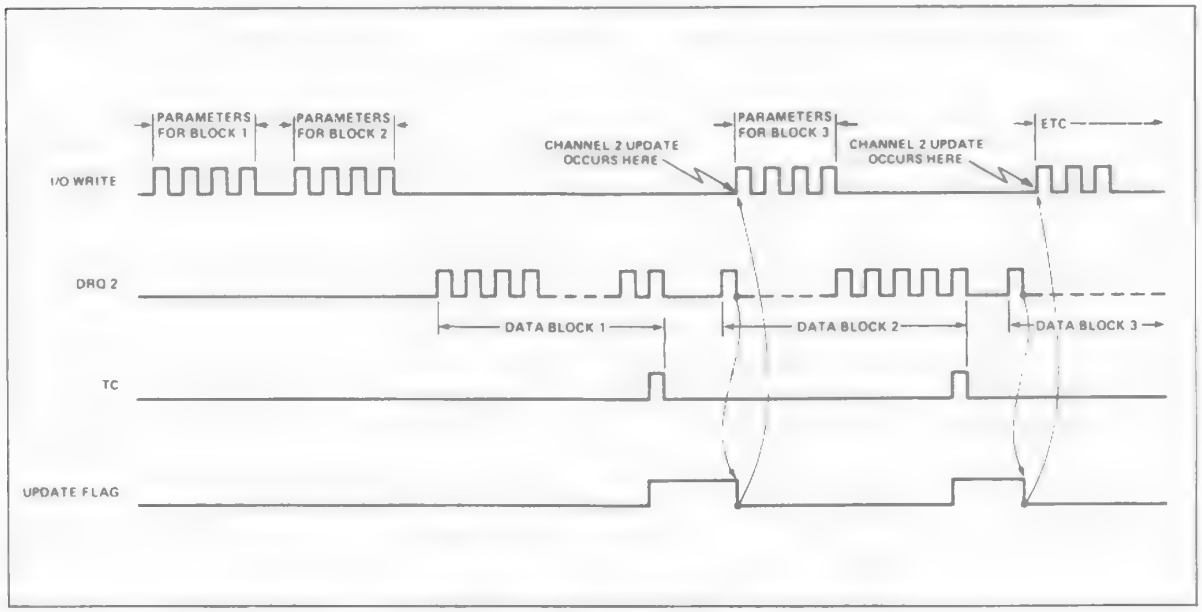


Figure 7. Autoload Timing

OPERATIONAL SUMMARY

Programming and Reading the 8257 Registers

There are four pairs of "channel registers": each pair consisting of a 16-bit DMA address register and a 16-bit terminal count register (one pair for each channel). The 8257 also includes two "general registers": one 8-bit Mode Set register and one 8-bit Status register. The registers are loaded or read when the CPU executes a write or read instruction that addresses the 8257 device and the appropriate register within the 8257. The 8228 generates the appropriate read or write control signal (generally I/OR or I/OW while the CPU places a 16-bit address on the system address bus, and either outputs the data to be written onto the system data bus or accepts the data being read from the data bus. All or some of the most significant 12 address bits A_4-A_{15} (depending on the systems memory, I/O configuration) are usually decoded to produce the chip select ($\overline{CS}$) input to the 8257. An I/O Write input (or Memory Write in memory mapped I/O configurations, described below) specifies that the addressed register is to be programmed, while an I/O Read input (or Memory Read) specifies that the addressed register is to be read. Address bit 3 specifies whether a "channel register" (A_3 = 0) or the Mode Set (program only)/Status (read only) register (A_3 = 1) is to be accessed.

The least significant three address bits, A_0-A_2, indicate the specific register to be accessed. When accessing the Mode Set or Status register, A_0-A_2 are all zero. When accessing a channel register bit A_0 differentiates between the DMA address register (A_0 = 0) and the terminal count register (A_0 = 1), while bits A_1 and A_2 specify one of the four channels. Because the "channel registers" are 16-bits, two program instruction cycles are required to load or read an entire register. The 8257 contains a first/last (F/L) flip flop which toggles at the completion of each channel program or read operation. The F/L flip flop determines whether the upper or lower byte of the register is to be accessed. The F/L flip flop is reset by the RESET input and whenever the Mode Set register is loaded. To maintain proper synchronization when accessing the "channel registers" all channel command instruction operations should occur in pairs, with the lower byte of a register always being accessed first. Do not allow $\overline{CS}$ to clock while either $\overline{I/OR}$ or $\overline{I/OW}$ is active, as this will cause an erroneous F/L flip flop state. In systems utilizing an interrupt structure, interrupts should be disabled prior to any paired programming operations to prevent an interrupt from splitting them. The result of such a split would leave the F/L F/F in the wrong state. This problem is particularly obvious when other DMA channels are programmed by an interrupt structure.

CONTROL INPUT	$\overline{CS}$	$\overline{I/OW}$	$\overline{I/OR}$	A_3
Program Half of a Channel Register	0	0	1	0
Read Half of a Channel Register	0	1	0	0
Program Mode Set Register	0	0	1	1
Read Status Register	0	1	0	1

8257 Register Selection

REGISTER	BYTE	ADDRESS INPUTS				F/L	*BI-DIRECTIONAL DATA BUS							
		A_3	A_2	A_1	A_0		D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CH-0 DMA Address	LSB	0	0	0	0	0	A_7	A_6	A_5	A_4	A_3	A_2	A_1	A_0
	MSB	0	0	0	0	1	A_{15}	A_{14}	A_{13}	A_{12}	A_{11}	A_{10}	A_9	A_8
CH-0 Terminal Count	LSB	0	0	0	1	0	C_7	C_6	C_5	C_4	C_3	C_2	C_1	C_0
	MSB	0	0	0	1	1	Rd	Wr	C_{13}	C_{12}	C_{11}	C_{10}	C_9	C_8
CH-1 DMA Address	LSB	0	0	1	0	0	Same as Channel 0							
	MSB	0	0	1	0	1								
CH-1 Terminal Count	LSB	0	0	1	1	0								
	MSB	0	0	1	1	1								
CH-2 DMA Address	LSB	0	1	0	0	0	Same as Channel 0							
	MSB	0	1	0	0	1								
CH-2 Terminal Count	LSB	0	1	0	1	0								
	MSB	0	1	0	1	1								
CH-3 DMA Address	LSB	0	1	1	0	0	Same as Channel 0							
	MSB	0	1	1	0	1								
CH-3 Terminal Count	LSB	0	1	1	1	0								
	MSB	0	1	1	1	1								
MODE SET (Program only)	—	1	0	0	0	0	AL	TCS	EW	RP	EN3	EN2	EN1	EN0
STATUS (Read only)	—	1	0	0	0	0	0	0	0	UP	TC3	TC2	TC1	TC0

*A_0-A_{15}: DMA Starting Address, C_0-C_{13}: Terminal Count value (N-1), Rd and Wr: DMA Verify (00), Write (01) or Read (10) cycle selection, AL: Auto Load, TCS: TC STOP, EW: EXTENDED WRITE, RP: ROTATING PRIORITY, EN3-EN0: CHANNEL ENABLE MASK, UP: UPDATE FLAG, TC3-TC0: TERMINAL COUNT STATUS BITS.

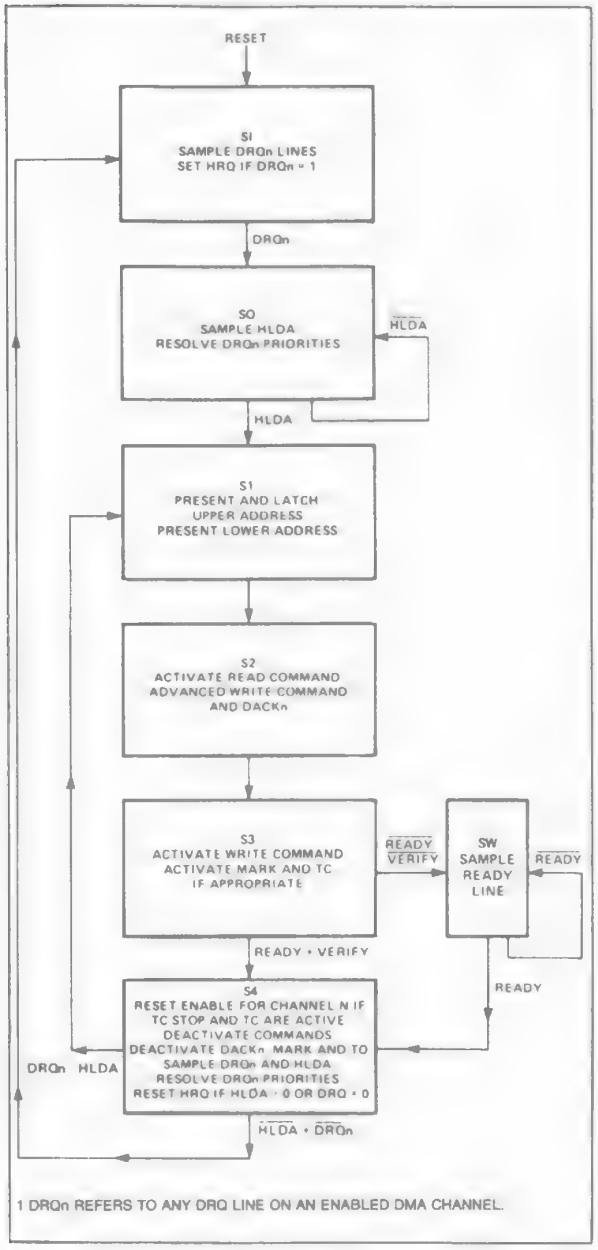


Figure 8. DMA Operation State Diagram

DMA OPERATION

Single Byte Transfers

A single byte transfer is initiated by the I/O device raising the DRQ line of one channel of the 8257. If the channel is enabled, the 8257 will output a HRQ to the CPU. The 8257 now waits until a HLDA is received insuring that the system bus is free for its use. Once HLDA is received the $\overline{\text{DACK}}$ line for the requesting channel is activated (LOW). The $\overline{\text{DACK}}$ line acts as a chip select for the requesting I/O device. The 8257 then generates the read and write commands and byte transfer occurs between the selected I/O device and memory. After the transfer is complete, the $\overline{\text{DACK}}$ line is set HIGH and the HRQ line is set LOW to indicate to the CPU that the bus is now free for use. DRQ must remain HIGH until $\overline{\text{DACK}}$ is issued to be recognized and must go LOW before S4 of the transfer sequence to prevent another transfer from occuring. (See timing diagram.)

Consecutive Transfers

If more than one channel requests service simultaneously, the transfer will occur in the same way a burst does. No overhead is incurred by switching from one channel to another. In each S4 the DRQ lines are sampled and the highest priority request is recognized during the next transfer. A burst mode transfer in a lower priority channel will be overridden by a higher priority request. Once the high priority transfer has completed control will return to the lower priority channel if its DRQ is still active. No extra cycles are needed to execute this sequence and the HRQ line remains active until all DRQ lines go LOW.

Control Override

The continuous DMA transfer mode described above can be interrupted by an external device by lowering the HLDA line. After each DMA transfer the 8257 samples the HLDA line to insure that it is still active. If it is not active, the 8257 completes the current transfer, releases the HRQ line (LOW) and returns to the idle state. If DRQ lines are still active the 8257 will raise the HRQ line in the third cycle and proceed normally. (See timing diagram.)

Not Ready

The 8257 has a Ready input similar to the 8080A and the 8085A. The Ready line is sampled in State 3. If Ready is LOW the 8257 enters a wait state. Ready is sampled during every wait state. When Ready returns HIGH the 8257 proceeds to State 4 to complete the transfer. Ready is used to interface memory or I/O devices that cannot meet the bus set up times required by the 8257.

Speed

The 8257 uses four clock cycles to transfer a byte of data. No cycles are lost in the master to master transfer maximizing bus efficiency. A 2MHz clock input will allow the 8257 to transfer at a rate of 500K bytes/second.

Memory Mapped I/O Configurations

The 8257 can be connected to the system bus as a memory device instead of as an I/O device for memory mapped I/O configurations by connecting the system memory control lines to the 8257's I/O control lines and the system I/O control lines to the 8257's memory control lines.

This configuration permits use of the 8080's considerably larger repertoire of memory instructions when reading or loading the 8257's registers. Note that with this connection, the programming of the Read (bit 15) and Write (bit 14) bits in the terminal count register will have a different meaning:

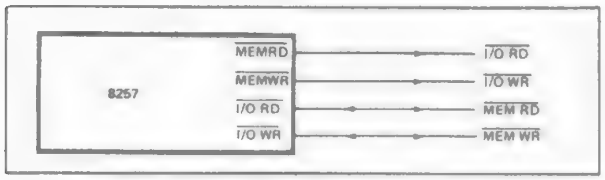


Figure 9. System Interface for Memory Mapped I/O

BIT 15 READ	BIT 14 WRITE	
0	0	DMA Verify Cycle
0	1	DMA Read Cycle
1	0	DMA Write Cycle
1	1	Illegal

Figure 10. TC Register for Memory Mapped I/O Only

SYSTEM APPLICATION EXAMPLES

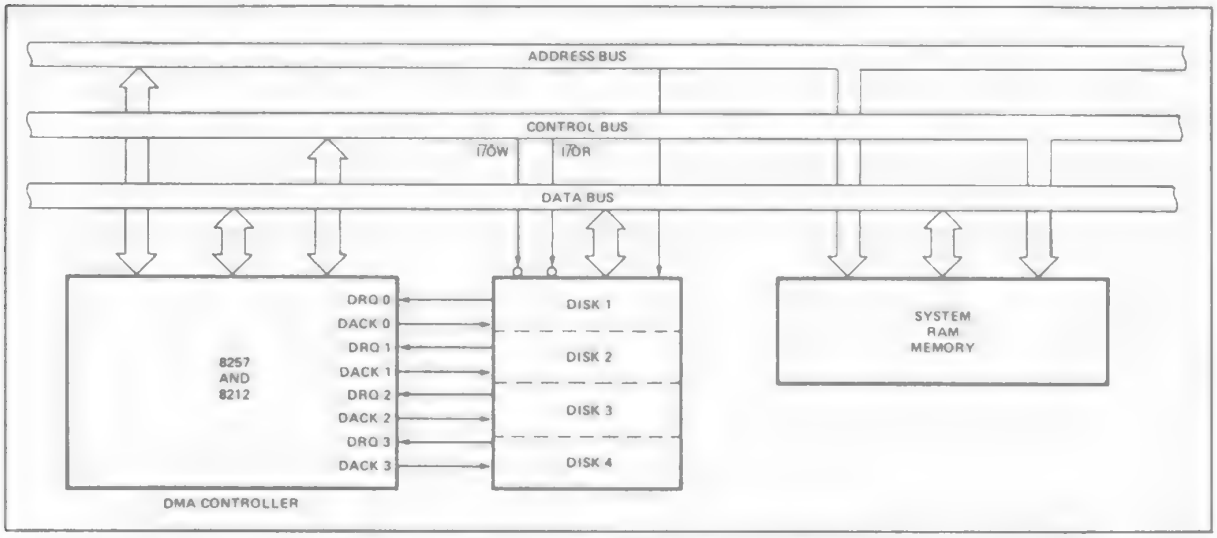


Figure 11. Floppy Disk Controller (4 Drives)

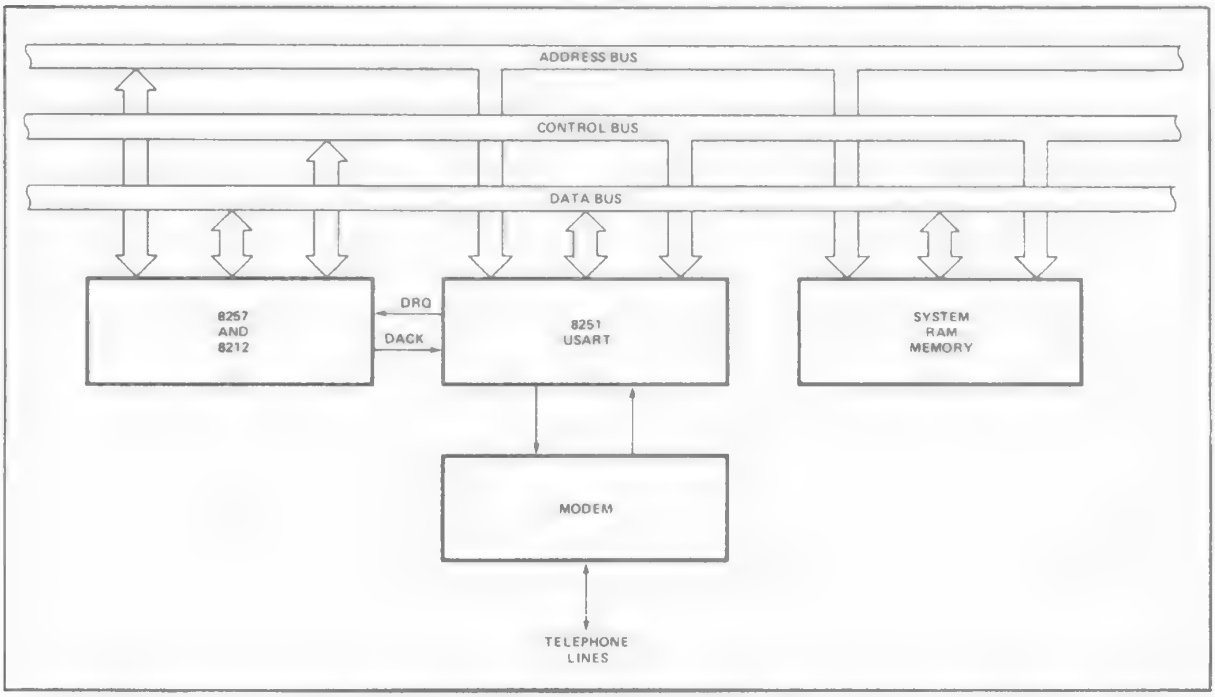
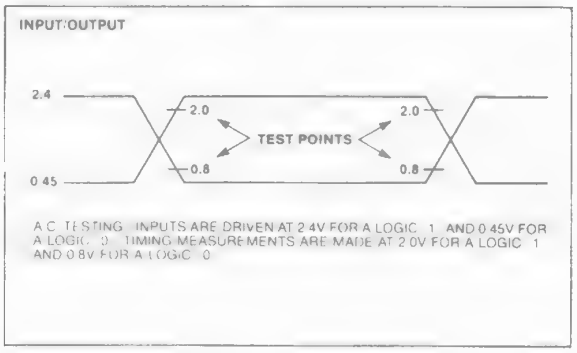
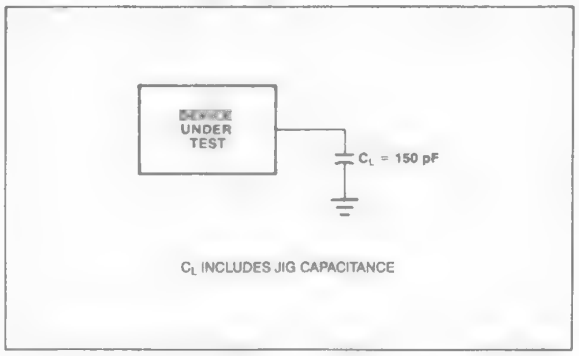


Figure 12. High-Speed Communication Controller

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING LOAD CIRCUIT



Tracking Parameters

Signals labeled as Tracking Parameters (footnotes 1 and 5-7 under A.C. Specifications) are signals that follow similar paths through the silicon die. The propagation speed of these signals varies in the manufacturing process but the relationship between all these parameters is constant. The variation is less than or equal to 50 ns.

Suppose the following timing equation is being evaluated,

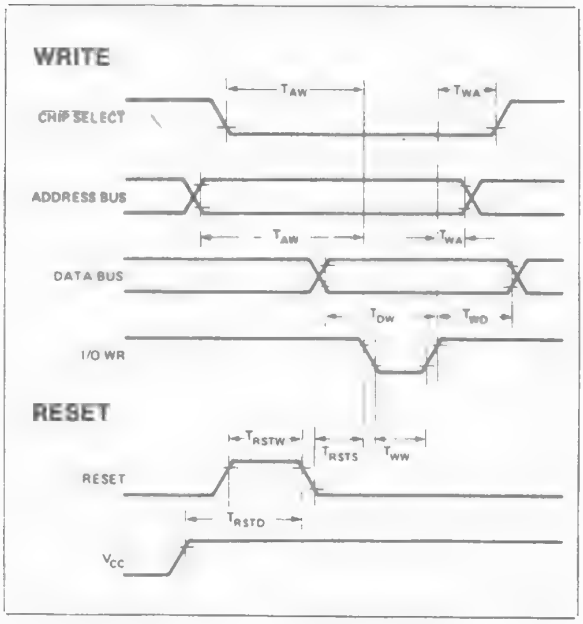
$$T_{A(MIN)} + T_{B(MAX)} \leq 150 \text{ ns}$$

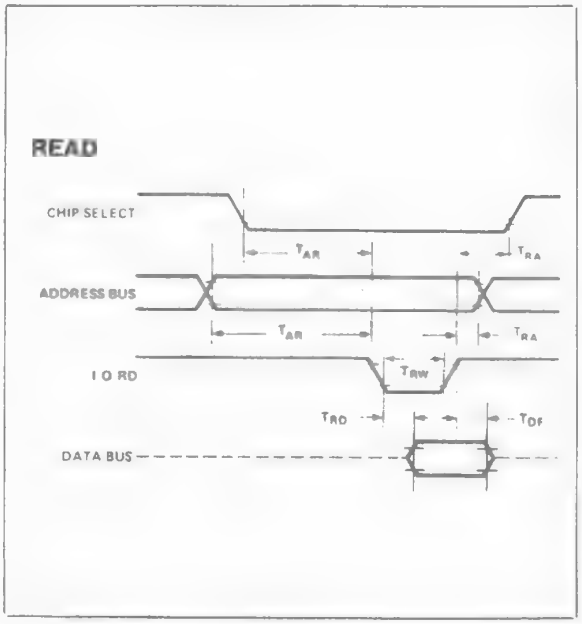
and only minimum specifications exist for T_A and T_B. If $T_{A(MIN)}$ is used, and if T_A and T_B are tracking parameters, $T_{B(MAX)}$ can be taken as $T_{B(MIN)}$ + 50 ns.

$$T_{A(MIN)} + (T_{B(MIN)}^{*} + 50 \text{ ns}) \leq 150 \text{ ns}$$

*If T_A and T_B are tracking parameters

WAVEFORMS—PERIPHERAL MODE

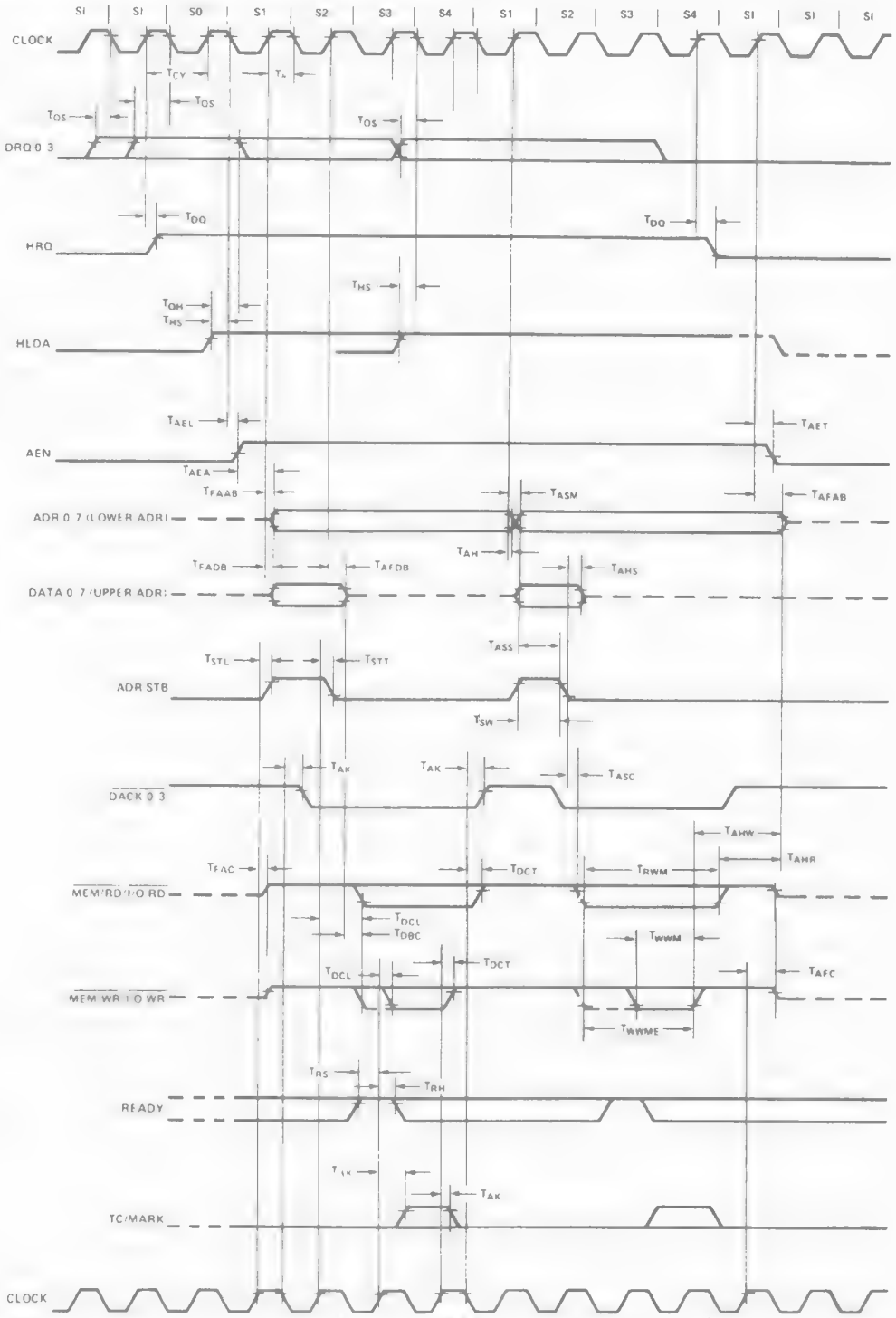




AFN-01840D

WAVEFORMS—DMA

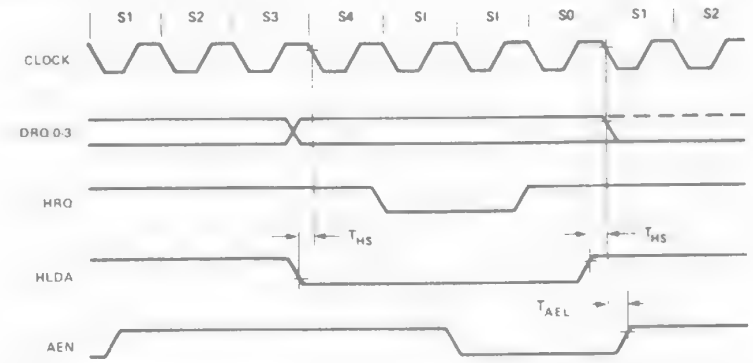
CONSECUTIVE CYCLES AND BURST MODE SEQUENCE



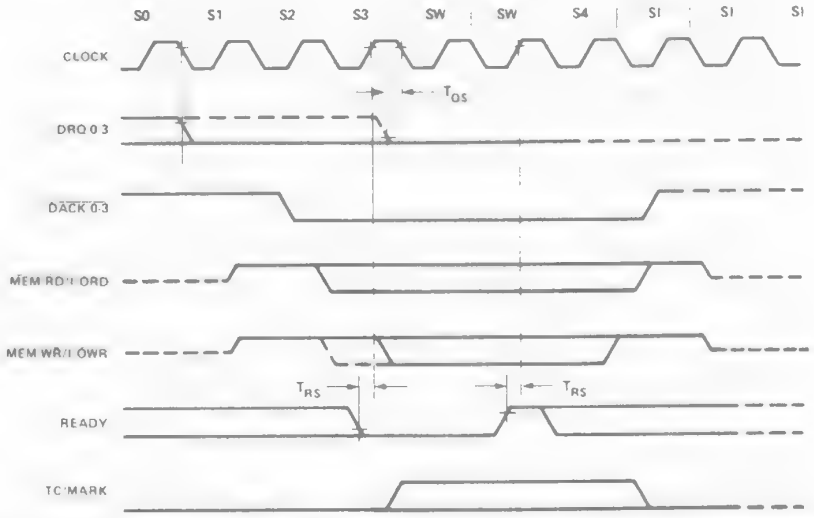
NOTE The clock waveform is duplicated for clarity. The 8257 requires only one clock input

WAVEFORMS (Continued)

CONTROL OVERRIDE SEQUENCE



NOT READY SEQUENCE



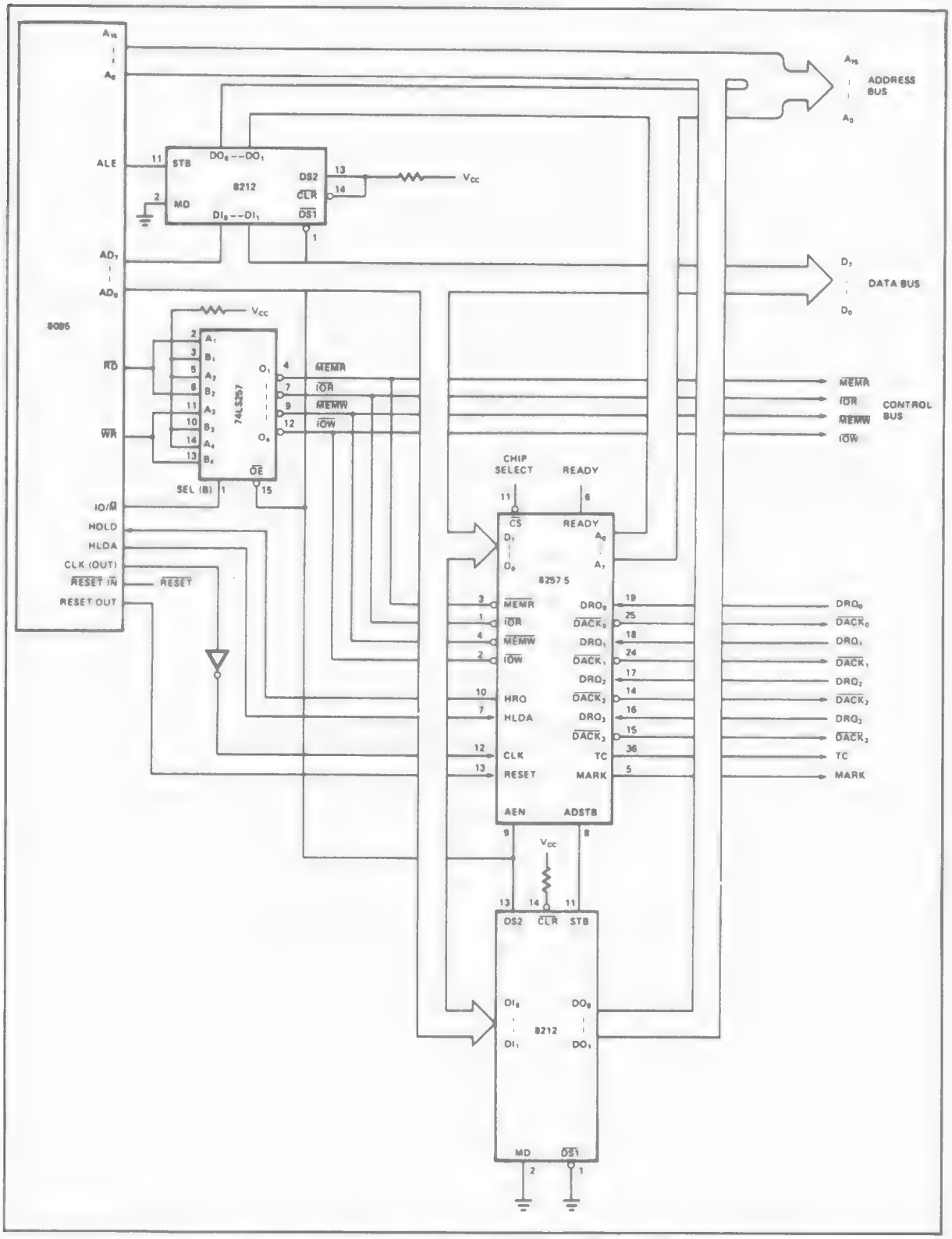


Figure 13. Detailed System Interface Schematic

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage on Any Pin
With Respect to Ground ..... −0.5V to +7V
Power Dissipation ..... 1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS

(8257: T_A = 0°C to 70°C, V_{CC} = 5.0V ±5%, GND = 0V)
(8257-5: T_A = 0°C to 70°C, V_{CC} = 5.0V ±10%, GND = 0V)

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_{IL}	Input Low Voltage	-0.5	0.8	Volts	
V_{IH}	Input High Voltage	2.0	V_{CC}+.5	Volts	
V_{OL}	Output Low Voltage		0.45	Volts	I_{OL} = 1.6 mA
V_{OH}	Output High Voltage	2.4	V_{CC}	Volts	I_{OH}=-150μA for AB, DB and AEN I_{OH}=-80μA for others
V_{HH}	HRQ Output High Voltage	3.3	V_{CC}	Volts	I_{OH} = -80μA
I_{CC}	V_{CC} Current Drain		120	mA	
I_{IL}	Input Leakage		±10	μA	$0V \leq V_{IN} \leq V_{CC}$
I_{OFL}	Output Leakage During Float		±10	μA	$0.45V \leq V_{OUT} \leq V_{CC}$

CAPACITANCE

(T_A = 25°C; V_{CC} = GND = 0V)

Symbol	Parameter	Min.	Typ.	Max.	Unit	Test Conditions
C_{IN}	Input Capacitance			10	pF	fc = 1MHz
$C_{I/O}$	I/O Capacitance			20	pF	Unmeasured pins returned to GND

A.C. CHARACTERISTICS—PERIPHERAL (SLAVE) MODE

(8257: T_A = 0°C to 70°C, V_{CC} = 5.0V ±5%, GND = 0V)
(8257-5: T_A = 0°C to 70°C, V_{CC} = 5.0V ±10%, GND = 0V)

8080 Bus Parameters

READ CYCLE

Symbol	Parameter	8257		8257-5		Unit	Test Conditions
		Min.	Max.	Min.	Max.		
T_{AR}	Adr or $\overline{CS}$↓ Setup to $\overline{RD}$↓	0		0		ns	
T_{RA}	Adr or $\overline{CS}$↑ Hold from $\overline{RD}$↑	0		0		ns	
T_{RD}	Data Access from $\overline{RD}$↓	0	300	0	220	ns	
T_{DF}	DB→Float Delay from $\overline{RD}$↑	20	150	20	120	ns	
T_{RR}	$\overline{RD}$ Width	250		250		ns	

WRITE CYCLE

Symbol	Parameter	8257		8257-5		Unit	Test Conditions
		Min.	Max.	Min.	Max.		
T_{AW}	Adr Setup to $\overline{WR}$↓	20		20		ns	
T_{WA}	Adr Hold from $\overline{WR}$↑	0		0		ns	
T_{DW}	Data Setup to $\overline{WR}$↑	200		200		ns	
T_{WD}	Data Hold from $\overline{WR}$↑	10		10		ns	
T_{WW}	$\overline{WR}$ Width	200		200		ns	

OTHER TIMING

Symbol	Parameter	8257		8257-5		Unit	Test Conditions
		Min.	Max.	Min.	Max.		
T_{RSTW}	Reset Pulse Width	300		300		ns	
T_{RSTD}	Power Supply↑ (V_{CC}) Setup to Reset↓	500		500		μs	
T_r	Signal Rise Time		20		20	ns	
T_f	Signal Fall Time		20		20	ns	
T_{RSTS}	Reset to First $\overline{I/OWR}$	2		2		t_{CY}	

A.C. CHARACTERISTICS—DMA (MASTER) MODE

(8257: T_A = 0°C to 70°C, V_{CC} = 5.0V ±5%, GND = 0V)
(8257-5: T_A = 0°C to 70°C, V_{CC} = 5.0V ±10%, GND = 0V)

TIMING REQUIREMENTS

Symbol	Parameter	8257		8257-5		Unit
		Min.	Max.	Min.	Max.	
T_{CY}	Cycle Time (Period)	0.320	4	0.320	4	μs
T_θ	Clock Active (High)	120	$.8T_{CY}$	80	$.8T_{CY}$	ns
T_{QS}	DRQ1 Setup to CLK1 (SI, S4)	120		120		ns
T_{QH}	DRQ1 Hold from HLDA1[1]	0		0		ns
T_{HS}	HLDA1 or 1Setup to CLK1(SI, S4)	100		100		ns
T_{RS}	READY Setup Time to CLK1(S3, Sw)	30		30		ns
T_{RH}	READY Hold Time from CLK1(S3, Sw)	30		30		ns

A.C. CHARACTERISTICS—DMA (MASTER) MODE

(8257: T_A = 0°C to 70°C, V_{CC} = 5.0V ±5%, GND = 0V)
(8257-5: T_A = 0°C to 70°C, V_{CC} = 5.0V ±10%, GND = 0V)

TIMING RESPONSES

Symbol	Parameter	8257		8257-5		Unit
		Min.	Max.	Min.	Max.	
T_{DQ}	HRQ↑ or ↓Delay from CLK↑ (SI, S4) (measured at 2.0V)		160		160	ns
T_{DQ1}	HRQ↑ or ↓Delay from CLK↑ (SI, S4) (measured at 3.3V)[3]		250		250	ns
T_{AEL}	AEN↑ Delay from CLK↓ (S1)		300		300	ns
T_{AET}	AEN↓ Delay from CLK↑ (SI)		200		200	ns
T_{AEA}	Adr (AB) (Active) Delay from AEN↑ (S1)[1]	20		20		ns
T_{FAAB}	Adr (AB) (Active) Delay from CLK↑ (S1)[2]		250		250	ns
T_{AFAB}	Adr (AB) (Float) Delay from CLK↑ (SI)[2]		150		150	ns
T_{ASM}	Adr (AB) (Stable) Delay from CLK↑ (S1)[2]		250		250	ns
T_{AH}	Adr (AB) (Stable) Hold from CLK↑ (S1)[2]	$T_{ASM}-50$		$T_{ASM}-50$		ns
T_{AHR}	Adr (AB) (Valid) Hold from $\overline{RD}$↑ (S1, SI)[1]	60		60		ns
T_{AHW}	Adr (AB) (Valid) Hold from $\overline{Wr}$↑ (S1, SI)[1]	300		300		ns
T_{FADB}	Adr (DB) (Active) Delay from CLK↑ (S1)[2]		300		300	ns
T_{AFDB}	Adr (DB) (Float) Delay from CLK↑ (S2)[2]	$T_{STT}+20$	250	$T_{STT}+20$	170	ns
T_{ASS}	Adr (DB) Setup to Adr Stb↓ (S1-S2)[1]	100		100		ns
T_{AHS}	Adr (DB) (Valid) Hold from Adr Stb↓ (S2)[1]	20		20		ns
T_{STL}	Adr Stb↑ Delay from CLK↑ (S1)		200		200	ns
T_{STT}	Adr Stb↓ Delay from CLK↑ (S2)		140		140	ns
T_{SW}	Adr Stb Width (S1-S2)[1]	$T_{CY}-100$		$T_{CY}-100$		ns
T_{ASC}	Rd↓ or $\overline{Wr}$(Ext)↓ Delay from Adr Stb↓ (S2)[1]	70		70		ns
T_{DBC}	$\overline{RD}$↓ or $\overline{WR}$(Ext)↓ Delay from Adr (DB) (Float) (S2)[1]	20		20		ns
T_{AK}	DACK↑ or ↓Delay from CLK↓ (S2, S1) and TC/Mark↑ Delay from CLK↑ (S3) and TC/Mark↓ Delay from CLK↑ (S4)[4]		250		250	ns
T_{DCL}	$\overline{RD}$↓ or $\overline{Wr}$(Ext)↓ Delay from CLK↑ (S2) and Wr↓ Delay from CLK↑ (S3)[2,5]		200		200	ns
T_{DCT}	Rd↑ Delay from CLK↓ (S1, SI) and Wr↑ Delay from CLK↑ (S4)[2,6]		200		200	ns
T_{FAC}	$\overline{Rd}$ or Wr (Active) from CLK↑ (S1)[2]		300		300	ns
T_{AFC}	$\overline{Rd}$ or $\overline{Wr}$ (Active) from CLK↑ (S1)[2]		150		150	ns
T_{RWM}	$\overline{Rd}$ Width (S2-S1 or SI)[1]	$2T_{CY}+T_{\theta}-50$		$2T_{CY}+T_{\theta}-50$		ns
T_{WWM}	$\overline{Wr}$ Width (S3-S4)[1]	$T_{CY}-50$		$T_{CY}-50$		ns
T_{WWME}	$\overline{WR}$(Ext) Width (S2-S4)[1]	$2T_{CY}-50$		$2T_{CY}-50$		ns

NOTES:
1. Tracking Parameter.
2. Load = + 50 pF.
3. Load = V_{OH} = 3.3V.
4. $\Delta T_{AK} < 50$ ns.
5. $\Delta T_{DCL} < 50$ ns.
6. $\Delta T_{DCT} < 50$ ns.

8259A/8259A-2/8259A-8
PROGRAMMABLE INTERRUPT CONTROLLER

- iAPX 86, iAPX 88 Compatible
- MCS-80®, MCS-85® Compatible
- Eight-Level Priority Controller
- Expandable to 64 Levels
- Programmable Interrupt Modes
- Individual Request Mask Capability
- Single +5V Supply (No Clocks)
- 28-Pin Dual-In-Line Package
- Available in EXPRESS
  - Standard Temperature Range
  - Extended Temperature Range

The Intel® 8259A Programmable Interrupt Controller handles up to eight vectored priority interrupts for the CPU. It is cascadable for up to 64 vectored priority interrupts without additional circuitry. It is packaged in a 28-pin DIP, uses NMOS technology and requires a single +5V supply. Circuitry is static, requiring no clock input.

The 8259A is designed to minimize the software and real time overhead in handling multi-level priority interrupts. It has several modes, permitting optimization for a variety of system requirements.

The 8259A is fully upward compatible with the Intel® 8259. Software originally written for the 8259 will operate the 8259A in all 8259 equivalent modes (MCS-80/85, Non-Buffered, Edge Triggered).

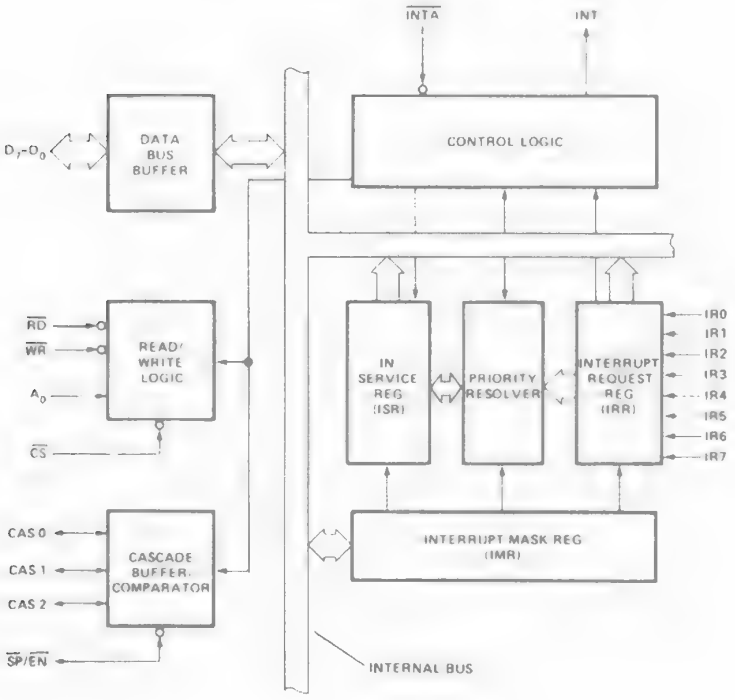


Figure 1. Block Diagram

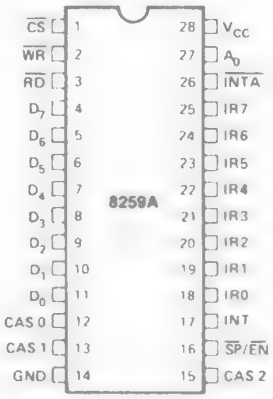


Figure 2. Pin Configuration

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
V_{CC}	28	I	**Supply:** +5V Supply.
GND	14	I	**Ground.**
$\overline{CS}$	1	I	**Chip Select:** A low on this pin enables $\overline{RD}$ and $\overline{WR}$ communication between the CPU and the 8259A. INTA functions are independent of CS.
$\overline{WR}$	2	O	**Write:** A low on this pin when CS is low enables the 8259A to accept command words from the CPU.
$\overline{RD}$	3	I	**Read:** A low on this pin when CS is low enables the 8259A to release status onto the data bus for the CPU.
D_7–D_0	4–11	I/O	**Bidirectional Data Bus:** Control, status and interrupt-vector information is transferred via this bus.
CAS_0–CAS_2	12, 13, 15	I/O	**Cascade Lines:** The CAS lines form a private 8259A bus to control a multiple 8259A structure. These pins are outputs for a master 8259A and inputs for a slave 8259A.
$\overline{SP}/\overline{EN}$	16	I/O	**Slave Program/Enable Buffer:** This is a dual function pin. When in the Buffered Mode it can be used as an output to control buffer transceivers (EN). When not in the buffered mode it is used as an input to designate a master (SP = 1) or slave (SP = 0).
INT	17	O	**Interrupt:** This pin goes high whenever a valid interrupt request is asserted. It is used to interrupt the CPU, thus it is connected to the CPU's interrupt pin.
IR_0–IR_7	18–25	I	**Interrupt Requests:** Asynchronous inputs. An interrupt request is executed by raising an IR input (low to high), and holding it high until it is acknowledged (Edge Triggered Mode), or just by a high level on an IR input (Level Triggered Mode).
$\overline{INTA}$	26	I	**Interrupt Acknowledge:** This pin is used to enable 8259A interrupt-vector data onto the data bus by a sequence of interrupt acknowledge pulses issued by the CPU.
A_0	27	I	**A0 Address Line:** This pin acts in conjunction with the $\overline{CS}$, $\overline{WR}$, and $\overline{RD}$ pins. It is used by the 8259A to decipher various Command Words the CPU writes and status the CPU wishes to read. It is typically connected to the CPU A0 address line (A1 for iAPX 86, 88).

FUNCTIONAL DESCRIPTION

Interrupts in Microcomputer Systems

Microcomputer system design requires that I/O devices such as keyboards, displays, sensors and other components receive servicing in an efficient manner so that large amounts of the total system tasks can be assumed by the microcomputer with little or no effect on throughput.

The most common method of servicing such devices is the *Polled* approach. This is where the processor must test each device in sequence and in effect "ask" each one if it needs servicing. It is easy to see that a large portion of the main program is looping through this continuous polling cycle and that such a method would have a serious, detrimental effect on system throughput, thus limiting the tasks that could be assumed by the microcomputer and reducing the cost effectiveness of using such devices.

A more desirable method would be one that would allow the microprocessor to be executing its main program and only stop to service peripheral devices when it is told to do so by the device itself. In effect, the method would provide an external asynchronous input that would inform the processor that it should complete whatever instruction that is currently being executed and fetch a new routine that will service the requesting device. Once this servicing is complete, however, the processor would resume exactly where it left off.

This method is called *Interrupt*. It is easy to see that system throughput would drastically increase, and thus more tasks could be assumed by the microcomputer to further enhance its cost effectiveness.

The Programmable Interrupt Controller (PIC) functions as an overall manager in an Interrupt-Driven system environment. It accepts requests from the peripheral equipment, determines which of the incoming requests is of the highest importance (priority), ascertains whether the incoming request has a higher priority value than the level currently being serviced, and issues an interrupt to the CPU based on this determination.

Each peripheral device or structure usually has a special program or "routine" that is associated with its specific functional or operational requirements; this is referred to as a "service routine". The PIC, after issuing an interrupt to the CPU, must somehow input information into the CPU that can "point" the Program Counter to the service routine associated with the requesting device. This "pointer" is an address in a vectoring table and will often be referred to, in this document, as vectoring data.

The 8259A

The 8259A is a device specifically designed for use in real time, interrupt driven microcomputer systems. It manages eight levels or requests and has built-in features for expandability to other 8259A's (up to 64 levels). It is programmed by the system's software as an I/O peripheral. A selection of priority modes is available to the programmer so that the manner in which the requests are processed by the 8259A can be configured to match his system requirements. The priority modes can be changed or reconfigured dynamically at any time during the main program. This means that the complete interrupt structure can be defined as required, based on the total system environment.

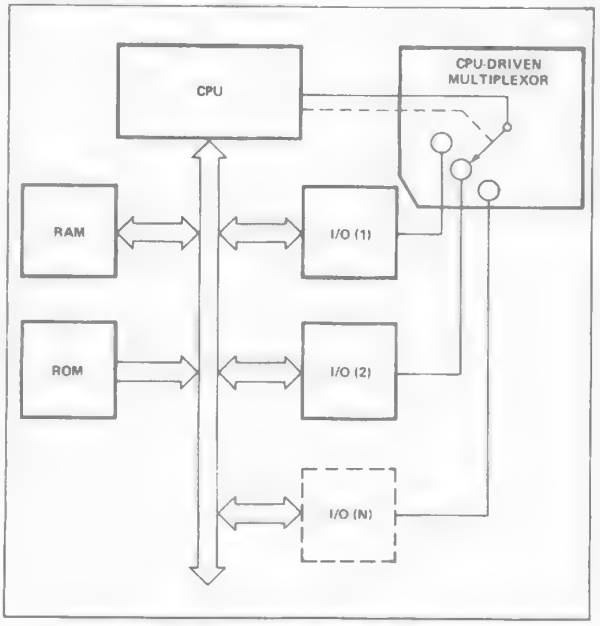


Figure 3a. Polled Method

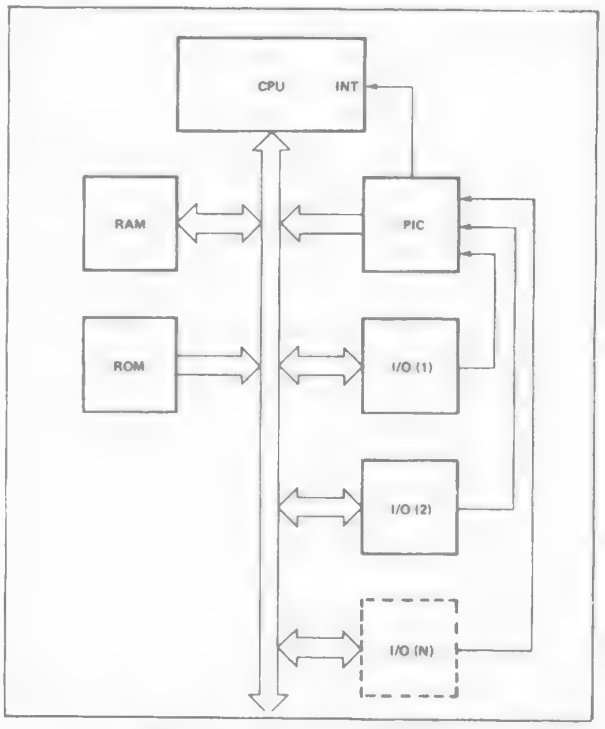


Figure 3b. Interrupt Method

INTERRUPT REQUEST REGISTER (IRR) AND IN-SERVICE REGISTER (ISR)

The interrupts at the IR input lines are handled by two registers in cascade, the Interrupt Request Register (IRR) and the In-Service Register (ISR). The IRR is used to store all the interrupt levels which are requesting service; and the ISR is used to store all the interrupt levels which are being serviced.

PRIORITY RESOLVER

This logic block determines the priorities of the bits set in the IRR. The highest priority is selected and strobed into the corresponding bit of the ISR during $\overline{INTA}$ pulse.

INTERRUPT MASK REGISTER (IMR)

The IMR stores the bits which mask the interrupt lines to be masked. The IMR operates on the IRR. Masking of a higher priority input will not affect the interrupt request lines of lower priority.

INT (INTERRUPT)

This output goes directly to the CPU interrupt input. The V_{OH} level on this line is designed to be fully compatible with the 8080A, 8085A and 8086 input levels.

$\overline{INTA}$ (INTERRUPT ACKNOWLEDGE)

$\overline{INTA}$ pulses will cause the 8259A to release vectoring information onto the data bus. The format of this data depends on the system mode (μPM) of the 8259A.

DATA BUS BUFFER

This 3-state, bidirectional 8-bit buffer is used to interface the 8259A to the system Data Bus. Control words and status information are transferred through the Data Bus Buffer.

READ/WRITE CONTROL LOGIC

The function of this block is to accept OUTput commands from the CPU. It contains the Initialization Command Word (ICW) registers and Operation Command Word (OCW) registers which store the various control formats for device operation. This function block also allows the status of the 8259A to be transferred onto the Data Bus.

$\overline{CS}$ (CHIP SELECT)

A LOW on this input enables the 8259A. No reading or writing of the chip will occur unless the device is selected.

$\overline{WR}$ (WRITE)

A LOW on this input enables the CPU to write control words (ICWs and OCWs) to the 8259A.

$\overline{RD}$ (READ)

A LOW on this input enables the 8259A to send the status of the Interrupt Request Register (IRR), In Service Register (ISR), the Interrupt Mask Register (IMR), or the Interrupt level onto the Data Bus.

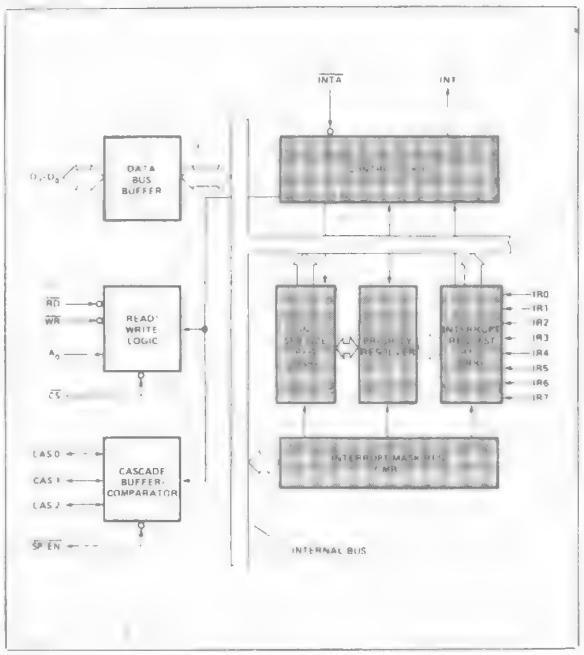


Figure 4a. 8259A Block Diagram

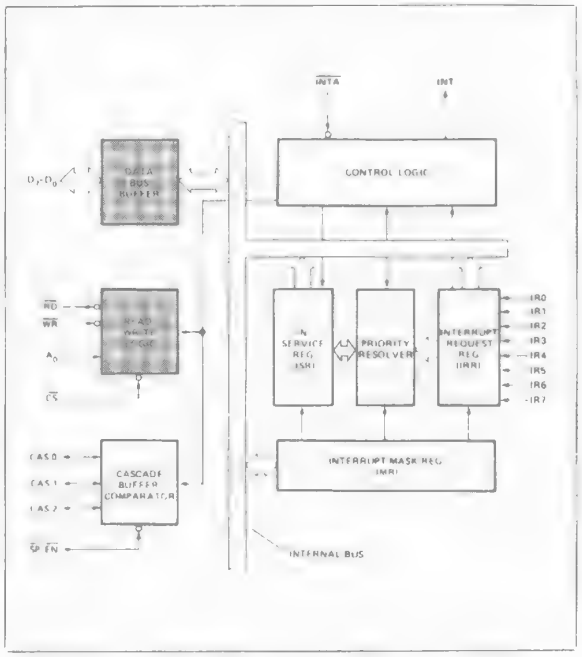


Figure 4b. 8259A Block Diagram

A_0

This input signal is used in conjunction with $\overline{WR}$ and $\overline{RD}$ signals to write commands into the various command registers, as well as reading the various status registers of the chip. This line can be tied directly to one of the address lines.

THE CASCADE BUFFER/COMPARATOR

This function block stores and compares the IDs of all 8259A's used in the system. The associated three I/O pins (CAS0-2) are outputs when the 8259A is used as a master and are inputs when the 8259A is used as a slave. As a master, the 8259A sends the ID of the interrupting slave device onto the CAS0-2 lines. The slave thus selected will send its preprogrammed subroutine address onto the Data Bus during the next one or two consecutive $\overline{INTA}$ pulses. (See section "Cascading the 8259A".)

INTERRUPT SEQUENCE

The powerful features of the 8259A in a microcomputer system are its programmability and the interrupt routine addressing capability. The latter allows direct or indirect jumping to the specific interrupt routine requested without any polling of the interrupting devices. The normal sequence of events during an interrupt depends on the type of CPU being used.

The events occur as follows in an MCS-80/85 system:

1. One or more of the INTERRUPT REQUEST lines (IR7-0) are raised high, setting the corresponding IRR bit(s).
2. The 8259A evaluates these requests, and sends an INT to the CPU, if appropriate.
3. The CPU acknowledges the INT and responds with an $\overline{INTA}$ pulse.
4. Upon receiving an $\overline{INTA}$ from the CPU group, the highest priority ISR bit is set, and the corresponding IRR bit is reset. The 8259A will also release a CALL instruction code (11001101) onto the 8-bit Data Bus through its D7-0 pins.
5. This CALL instruction will initiate two more $\overline{INTA}$ pulses to be sent to the 8259A from the CPU group.
6. These two $\overline{INTA}$ pulses allow the 8259A to release its preprogrammed subroutine address onto the Data Bus. The lower 8-bit address is released at the first $\overline{INTA}$ pulse and and the higher 8-bit address is released at the second $\overline{INTA}$ pulse.
7. This completes the 3-byte CALL instruction released by the 8259A. In the AEOI mode the ISR bit is reset at the end of the third $\overline{INTA}$ pulse. Otherwise, the ISR bit remains set until an appropriate EOI command is issued at the end of the interrupt sequence.

The events occurring in an iAPX 86 system are the same until step 4.

4. Upon receiving an $\overline{INTA}$ from the CPU group, the highest priority ISR bit is set and the corresponding IRR bit is reset. The 8259A does not drive the Data Bus during this cycle.
5. The iAPX 86/10 will initiate a second $\overline{INTA}$ pulse. During this pulse, the 8259A releases an 8-bit pointer onto the Data Bus where it is read by the CPU.
6. This completes the interrupt cycle. In the AEOI mode the ISR bit is reset at the end of the second $\overline{INTA}$ pulse. Otherwise, the ISR bit remains set until an appropriate EOI command is issued at the end of the interrupt subroutine.

If no interrupt request is present at step 4 of either sequence (i.e., the request was too short in duration) the 8259A will issue an interrupt level 7. Both the vectoring bytes and the CAS lines will look like an interrupt level 7 was requested.

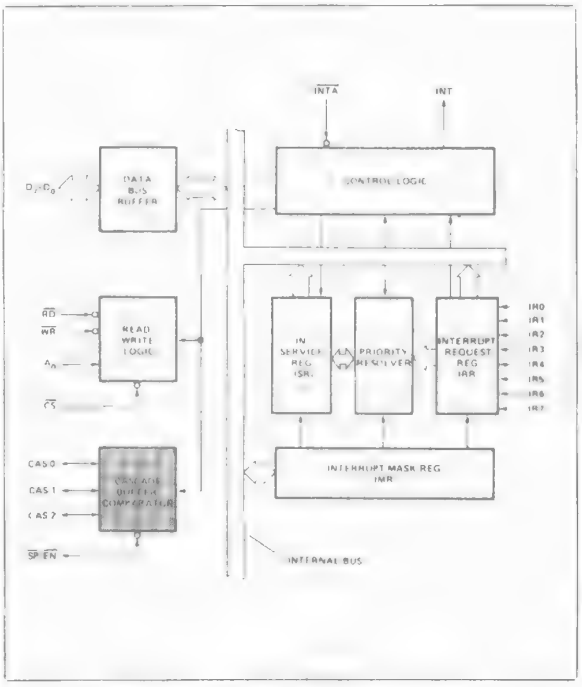


Figure 4c. 8259A Block Diagram

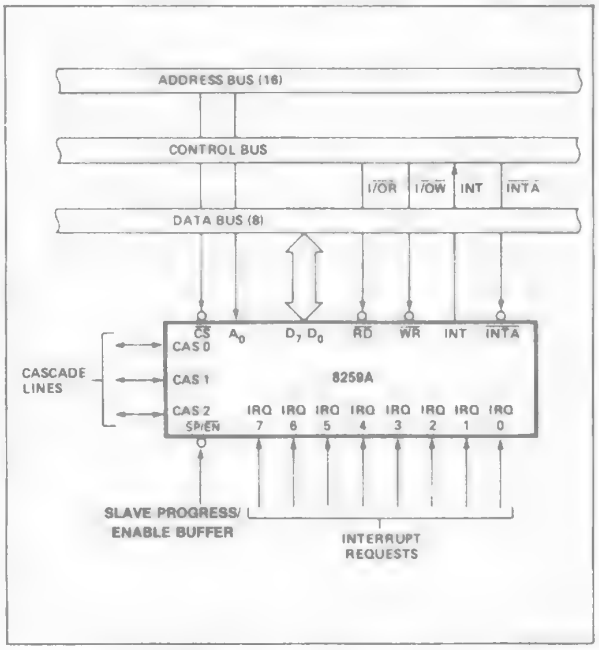


Figure 5. 8259A Interface to Standard System Bus

INTERRUPT SEQUENCE OUTPUTS

MCS-80®, MCS-85®

This sequence is timed by three $\overline{INTA}$ pulses. During the first $\overline{INTA}$ pulse the CALL opcode is enabled onto the data bus.

Content of First Interrupt Vector Byte

	D7	D6	D5	D4	D3	D2	D1	D0
CALL CODE	1	1	0	0	1	1	0	1

During the second $\overline{INTA}$ pulse the lower address of the appropriate service routine is enabled onto the data bus. When Interval = 4 bits A_5–A_7 are programmed, while A_0–A_4 are automatically inserted by the 8259A. When Interval = 8 only A_6 and A_7 are programmed, while A_0–A_5 are automatically inserted.

Content of Second Interrupt Vector Byte

IR	Interval = 4							
	D7	D6	D5	D4	D3	D2	D1	D0
7	A7	A6	A5	1	1	1	0	0
6	A7	A6	A5	1	1	0	0	0
5	A7	A6	A5	1	0	1	0	0
4	A7	A6	A5	1	0	0	0	0
3	A7	A6	A5	0	1	1	0	0
2	A7	A6	A5	0	1	0	0	0
1	A7	A6	A5	0	0	1	0	0
0	A7	A6	A5	0	0	0	0	0

IR	Interval = 8							
	D7	D6	D5	D4	D3	D2	D1	D0
7	A7	A6	1	1	1	0	0	0
6	A7	A6	1	1	0	0	0	0
5	A7	A6	1	0	1	0	0	0
4	A7	A6	1	0	0	0	0	0
3	A7	A6	0	1	1	0	0	0
2	A7	A6	0	1	0	0	0	0
1	A7	A6	0	0	1	0	0	0
0	A7	A6	0	0	0	0	0	0

During the third INTA pulse the higher address of the appropriate service routine, which was programmed as byte 2 of the initialization sequence (A_8 – A_{15}), is enabled onto the bus.

Content of Third Interrupt Vector Byte

D7	D6	D5	D4	D3	D2	D1	D0
A15	A14	A13	A12	A11	A10	A9	A8

iAPX 86, iAPX 88

iAPX 86 mode is similar to MCS-80 mode except that only two Interrupt Acknowledge cycles are issued by the processor and no CALL opcode is sent to the processor. The first interrupt acknowledge cycle is similar to that of MCS-80, 85 systems in that the 8259A uses it to internally freeze the state of the interrupts for priority resolution and as a master it issues the interrupt code on the cascade lines at the end of the INTA pulse. On this first cycle it does not issue any data to the processor and leaves its data bus buffers disabled. On the second interrupt acknowledge cycle in iAPX 86 mode the master (or slave if so programmed) will send a byte of data to the processor with the acknowledged interrupt code composed as follows (note the state of the ADI mode control is ignored and A_5–A_{11} are unused in iAPX 86 mode):

Content of Interrupt Vector Byte for iAPX 86 System Mode

	D7	D6	D5	D4	D3	D2	D1	D0
IR7	T7	T6	T5	T4	T3	1	1	1
IR6	T7	T6	T5	T4	T3	1	1	0
IR5	T7	T6	T5	T4	T3	1	0	1
IR4	T7	T6	T5	T4	T3	1	0	0
IR3	T7	T6	T5	T4	T3	0	1	1
IR2	T7	T6	T5	T4	T3	0	1	0
IR1	T7	T6	T5	T4	T3	0	0	1
IR0	T7	T6	T5	T4	T3	0	0	0

PROGRAMMING THE 8259A

The 8259A accepts two types of command words generated by the CPU:

1. *Initialization Command Words (ICWs):* Before normal operation can begin, each 8259A in the system must be brought to a starting point — by a sequence of 2 to 4 bytes timed by $\overline{WR}$ pulses.
2. *Operation Command Words (OCWs):* These are the command words which command the 8259A to operate in various interrupt modes. These modes are:
   a. Fully nested mode
   b. Rotating priority mode
   c. Special mask mode
   d. Polled mode

The OCWs can be written into the 8259A anytime after initialization.

INITIALIZATION COMMAND WORDS (ICWS)

GENERAL

Whenever a command is issued with A0 = 0 and D4 = 1, this is interpreted as Initialization Command Word 1 (ICW1). ICW1 starts the initialization sequence during which the following automatically occur.

a. The edge sense circuit is reset, which means that following initialization, an interrupt request (IR) input must make a low-to-high transition to generate an interrupt.
b. The Interrupt Mask Register is cleared.
c. IR7 input is assigned priority 7.
d. The slave mode address is set to 7.
e. Special Mask Mode is cleared and Status Read is set to IRR.
f. If IC4=0, then all functions selected in ICW4 are set to zero. (Non-Buffered mode*, no Auto-EOI, MCS-80, 85 system).

*Note: Master/Slave in ICW4 is only used in the buffered mode.

INITIALIZATION COMMAND WORDS 1 AND 2 (ICW1, ICW2)

A_5–A_{15}: *Page starting address of service routines.* In an MCS 80/85 system, the 8 request levels will generate CALLs to 8 locations equally spaced in memory. These can be programmed to be spaced at intervals of 4 or 8 memory locations, thus the 8 routines will occupy a page of 32 or 64 bytes, respectively.

The address format is 2 bytes long (A_0–A_{15}). When the routine interval is 4, A_0–A_4 are automatically inserted by the 8259A, while A_5–A_{15} are programmed externally. When the routine interval is 8, A_0–A_5 are automatically inserted by the 8259A, while A_6–A_{15} are programmed externally.

The 8-byte interval will maintain compatibility with current software, while the 4-byte interval is best for a compact jump table.

In an iAPX 86 system A_{15}–A_{11} are inserted in the five most significant bits of the vectoring byte and the 8259A sets the three least significant bits according to the interrupt level. A_{10}–A_5 are ignored and ADI (Address interval) has no effect.

LTIM: If LTIM = 1, then the 8259A will operate in the level interrupt mode. Edge detect logic on the interrupt inputs will be disabled.

ADI: CALL address interval. ADI = 1 then interval = 4; ADI = 0 then interval = 8.

SNGL: Single. Means that this is the only 8259A in the system. If SNGL = 1 no ICW3 will be issued.

IC4: If this bit is set — ICW4 has to be read. If ICW4 is not needed, set IC4 = 0.

INITIALIZATION COMMAND WORD 3 (ICW3)

This word is read only when there is more than one 8259A in the system and cascading is used, in which case SNGL = 0. It will load the 8-bit slave register. The functions of this register are:

a. In the master mode (either when SP = 1, or in buffered mode when M/S = 1 in ICW4) a "1" is set for each slave in the system. The master then will release byte 1 of the call sequence (for MCS-80/85 system) and will enable the corresponding slave to release bytes 2 and 3 (for iAPX 86 only byte 2) through the cascade lines.

b. In the slave mode (either when $\overline{SP}$ = 0, or if BUF = 1 and M/S = 0 in ICW4) bits 2-0 identify the slave. The slave compares its cascade input with these bits and, if they are equal, bytes 2 and 3 of the call sequence (or just byte 2 for iAPX 86 are released by it on the Data Bus.

INITIALIZATION COMMAND WORD 4 (ICW4)

SFNM: If SFNM = 1 the special fully nested mode is programmed.

BUF: If BUF = 1 the buffered mode is programmed. In buffered mode $\overline{SP}/\overline{EN}$ becomes an enable output and the master/slave determination is by M/S.

M/S: If buffered mode is selected: M/S = 1 means the 8259A is programmed to be a master, M/S = 0 means the 8259A is programmed to be a slave. If BUF = 0, M/S has no function.

AEOI: If AEOI = 1 the automatic end of interrupt mode is programmed.

μPM: Microprocessor mode: μPM = 0 sets the 8259A for MCS-80, 85 system operation, μPM = 1 sets the 8259A for iAPX 86 system operation.

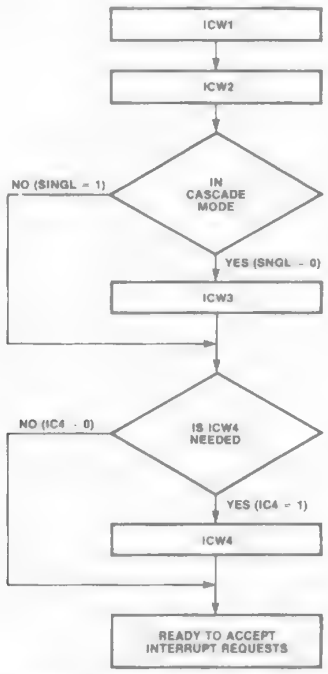


Figure 6. Initialization Sequence

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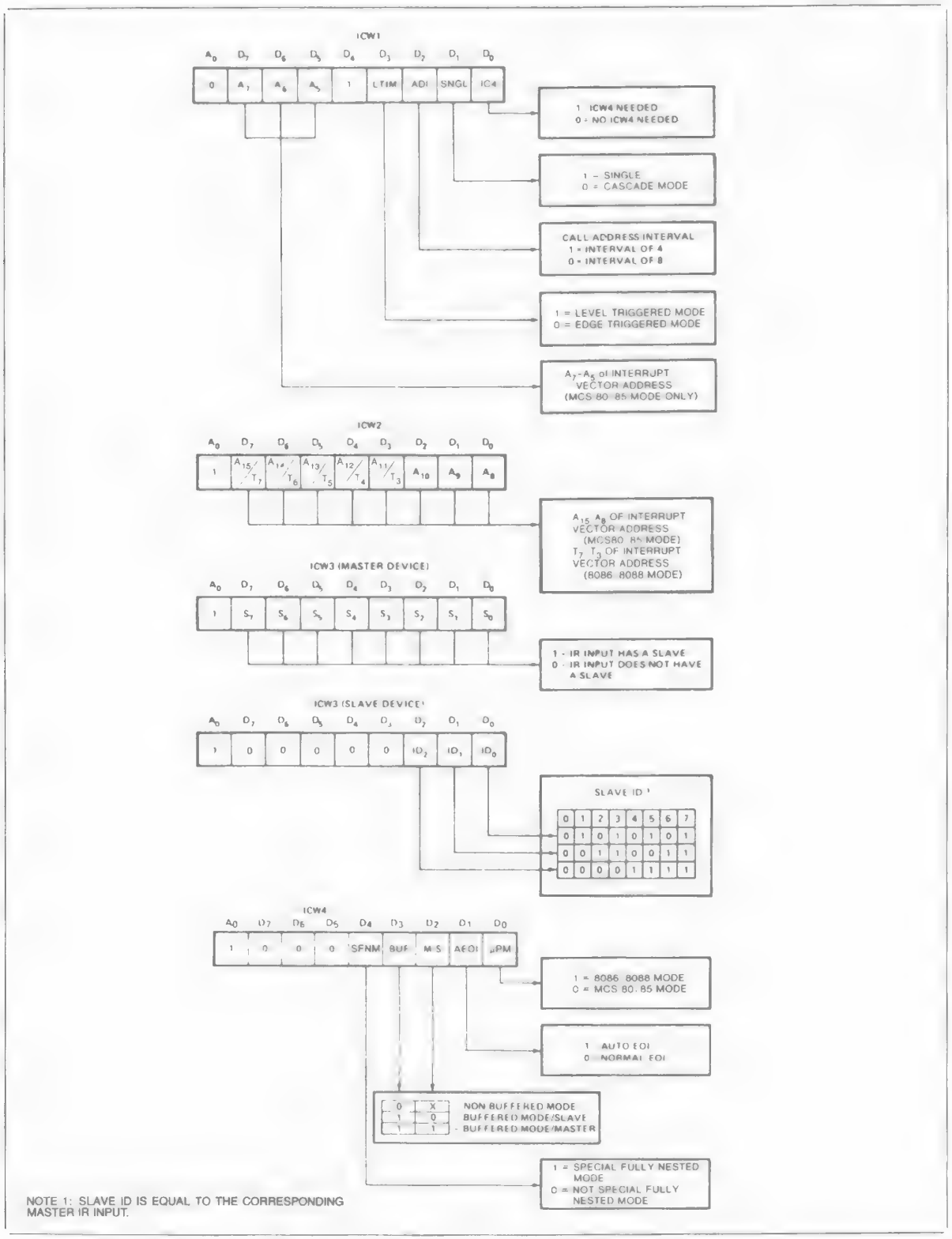

Figure 7. Initialization Command Word Format

OPERATION COMMAND WORDS (OCWs)

After the Initialization Command Words (ICWs) are programmed into the 8259A, the chip is ready to accept interrupt requests at its input lines. However, during the 8259A operation, a selection of algorithms can command the 8259A to operate in various modes through the Operation Command Words (OCWs).

OPERATION CONTROL WORDS (OCWs)

OCW1

A0	D7	D6	D5	D4	D3	D2	D1	D0
1	M7	M6	M5	M4	M3	M2	M1	M0

OCW2

0	R	SL	EOI	0	0	L2	L1	L0

OCW3

0	0	ESMM	SMM	0	1	P	RR	RIS

OPERATION CONTROL WORD 1 (OCW1)

OCW1 sets and clears the mask bits in the Interrupt Mask Register (IMR). $M_7 - M_0$ represent the eight mask bits. M = 1 indicates the channel is masked (inhibited), M = 0 indicates the channel is enabled.

OPERATION CONTROL WORD 2 (OCW2)

R, SL, EOI — These three bits control the Rotate and End of Interrupt modes and combinations of the two. A chart of these combinations can be found on the Operation Command Word Format.

L_2, L_1, L_0—These bits determine the interrupt level acted upon when the SL bit is active.

OPERATION CONTROL WORD 3 (OCW3)

ESMM — Enable Special Mask Mode. When this bit is set to 1 it enables the SMM bit to set or reset the Special Mask Mode. When ESMM = 0 the SMM bit becomes a "don't care".

SMM — Special Mask Mode. If ESMM = 1 and SMM = 1 the 8259A will enter Special Mask Mode. If ESMM = 1 and SMM = 0 the 8259A will revert to normal mask mode. When ESMM = 0, SMM has no effect.

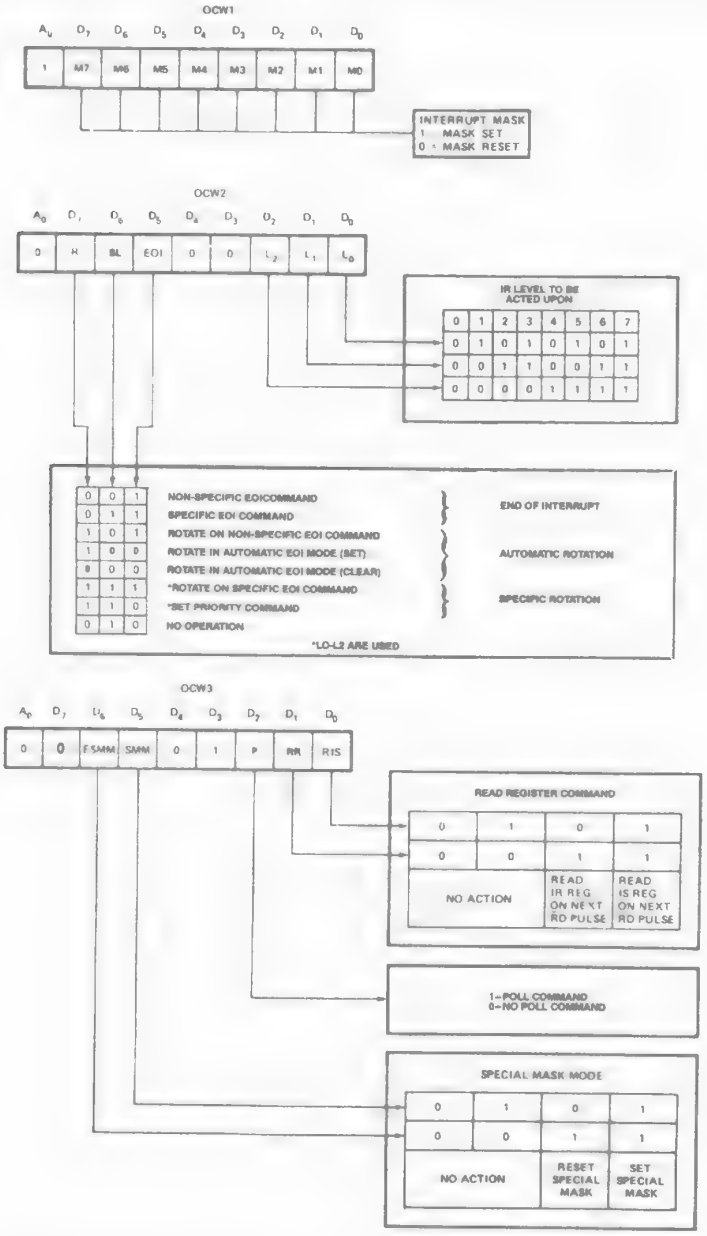

Figure 8. Operation Command Word Format

FULLY NESTED MODE

This mode is entered after initialization unless another mode is programmed. The interrupt requests are ordered in priority form 0 through 7 (0 highest). When an interrupt is acknowledged the highest priority request is determined and its vector placed on the bus. Additionally, a bit of the Interrupt Service register (ISO-7) is set. This bit remains set until the microprocessor issues an End of Interrupt (EOI) command immediately before returning from the service routine, or if AEOI (Automatic End of Interrupt) bit is set, until the trailing edge of the last INTA. While the IS bit is set, all further interrupts of the same or lower priority are inhibited, while higher levels will generate an interrupt (which will be acknowledged only if the microprocessor internal Interrupt enable flip-flop has been re-enabled through software).

After the initialization sequence, IR0 has the highest priority and IR7 the lowest. Priorities can be changed, as will be explained, in the rotating priority mode.

END OF INTERRUPT (EOI)

The In Service (IS) bit can be reset either automatically following the trailing edge of the last in sequence $\overline{\text{INTA}}$ pulse (when AEOI bit in ICW1 is set) or by a command word that must be issued to the 8259A before returning from a service routine (EOI command). An EOI command must be issued twice if in the Cascade mode, once for the master and once for the corresponding slave.

There are two forms of EOI command: Specific and Non-Specific. When the 8259A is operated in modes which preserve the fully nested structure, it can determine which IS bit to reset on EOI. When a Non-Specific EOI command is issued the 8259A will automatically reset the highest IS bit of those that are set, since in the fully nested mode the highest IS level was necessarily the last level acknowledged and serviced. A non-specific EOI can be issued with OCW2 (EOI = 1, SL = 0, R = 0).

When a mode is used which may disturb the fully nested structure, the 8259A may no longer be able to determine the last level acknowledged. In this case a Specific End of Interrupt must be issued which includes as part of the command the IS level to be reset. A specific EOI can be issued with OCW2 (EOI = 1, SL = 1, R = 0, and LO-L2 is the binary level of the IS bit to be reset).

It should be noted that an IS bit that is masked by an IMR bit will not be cleared by a non-specific EOI if the 8259A is in the Special Mask Mode.

AUTOMATIC END OF INTERRUPT (AEOI) MODE

If AEOI = 1 in ICW4, then the 8259A will operate in AEOI mode continuously until reprogrammed by ICW4. In this mode the 8259A will automatically perform a non-specific EOI operation at the trailing edge of the last interrupt acknowledge pulse (third pulse in MCS-80/85, second in iAPX 86). Note that from a system standpoint, this mode should be used only when a nested multilevel interrupt structure is not required within a single 8259A.

The AEOI mode can only be used in a master 8259A and not a slave.

AUTOMATIC ROTATION
(Equal Priority Devices)

In some applications there are a number of interrupting devices of equal priority. In this mode a device, after being serviced, receives the lowest priority, so a device requesting an interrupt will have to wait, in the worst case until each of 7 other devices are serviced at most *once*. For example, if the priority and "in service" status is:

Before Rotate (IR4 the highest priority requiring service)

	IS7	IS6	IS5	IS4	IS3	IS2	IS1	IS0
"IS" Status	0	1	0	1	0	0	0	0
	Lowest Priority							Highest Priority
Priority Status	7	6	5	4	3	2	1	0

After Rotate (IR4 was serviced, all other priorities rotated correspondingly)

	IS7	IS6	IS5	IS4	IS3	IS2	IS1	IS0
"IS" Status	0	1	0	0	0	0	0	0
	Highest Priority							Lowest Priority
Priority Status	2	1	0	7	6	5	4	3

There are two ways to accomplish Automatic Rotation using OCW2, the Rotation on Non-Specific EOI Command (R = 1, SL = 0, EOI = 1) and the Rotate in Automatic EOI Mode which is set by (R = 1, SL = 0, EOI = 0) and cleared by (R = 0, SL = 0, EOI = 0).

SPECIFIC ROTATION
(Specific Priority)

The programmer can change priorities by programming the bottom priority and thus fixing all other priorities; i.e., if IR5 is programmed as the bottom priority device, then IR6 will have the highest one.

The Set Priority command is issued in OCW2 where: R = 1, SL = 1; LO–L2 is the binary priority level code of the bottom priority device.

Observe that in this mode internal status is updated by software control during OCW2. However, it is independent of the End of Interrupt (EOI) command (also executed by OCW2). Priority changes can be executed during an EOI command by using the Rotate on Specific EOI command in OCW2 (R = 1, SL = 1, EOI = 1 and LO–L2 = IR level to receive bottom priority).

INTERRUPT MASKS

Each Interrupt Request input can be masked individually by the Interrupt Mask Register (IMR) programmed through OCW1. Each bit in the IMR masks one interrupt channel if it is set (1). Bit 0 masks IR0, Bit 1 masks IR1 and so forth. Masking an IR channel does not affect the other channels operation.

SPECIAL MASK MODE

Some applications may require an interrupt service routine to dynamically alter the system priority structure during its execution under software control. For example, the routine may wish to inhibit lower priority requests for a portion of its execution but enable some of them for another portion.

The difficulty here is that if an Interrupt Request is acknowledged and an End of Interrupt command did not reset its IS bit (i.e., while executing a service routine), the 8259A would have inhibited all lower priority requests with no easy way for the routine to enable them

That is where the Special Mask Mode comes in. In the special Mask Mode, when a mask bit is set in OCW1, it inhibits further interrupts at that level *and enables* interrupts from *all other* levels (lower as well as higher) that are not masked.

Thus, any interrupts may be selectively enabled by loading the mask register.

The special Mask Mode is set by OCW3 where: SSMM = 1, SMM = 1, and cleared where SSMM = 1, SMM = 0.

POLL COMMAND

In this mode the INT output is not used or the microprocessor internal Interrupt Enable flip-flop is reset, disabling its interrupt input. Service to devices is achieved by software using a Poll command.

The Poll command is issued by setting P = "1" in OCW3. The 8259A treats the next $\overline{RD}$ pulse to the 8259A (i.e., $\overline{RD} = 0$, $\overline{CS} = 0$) as an interrupt acknowledge, sets the appropriate IS bit if there is a request, and reads the priority level. Interrupt is frozen from $\overline{WR}$ to $\overline{RD}$.

The word enabled onto the data bus during $\overline{RD}$ is:

D7	D6	D5	D4	D3	D2	D1	D0
I	—	—	—	—	W2	W1	W0

W0–W2: Binary code of the highest priority level requesting service.

I: Equal to a "1" if there is an interrupt.

This mode is useful if there is a routine command common to several levels so that the $\overline{INTA}$ sequence is not needed (saves ROM space). Another application is to use the poll mode to expand the number of priority levels to more than 64.

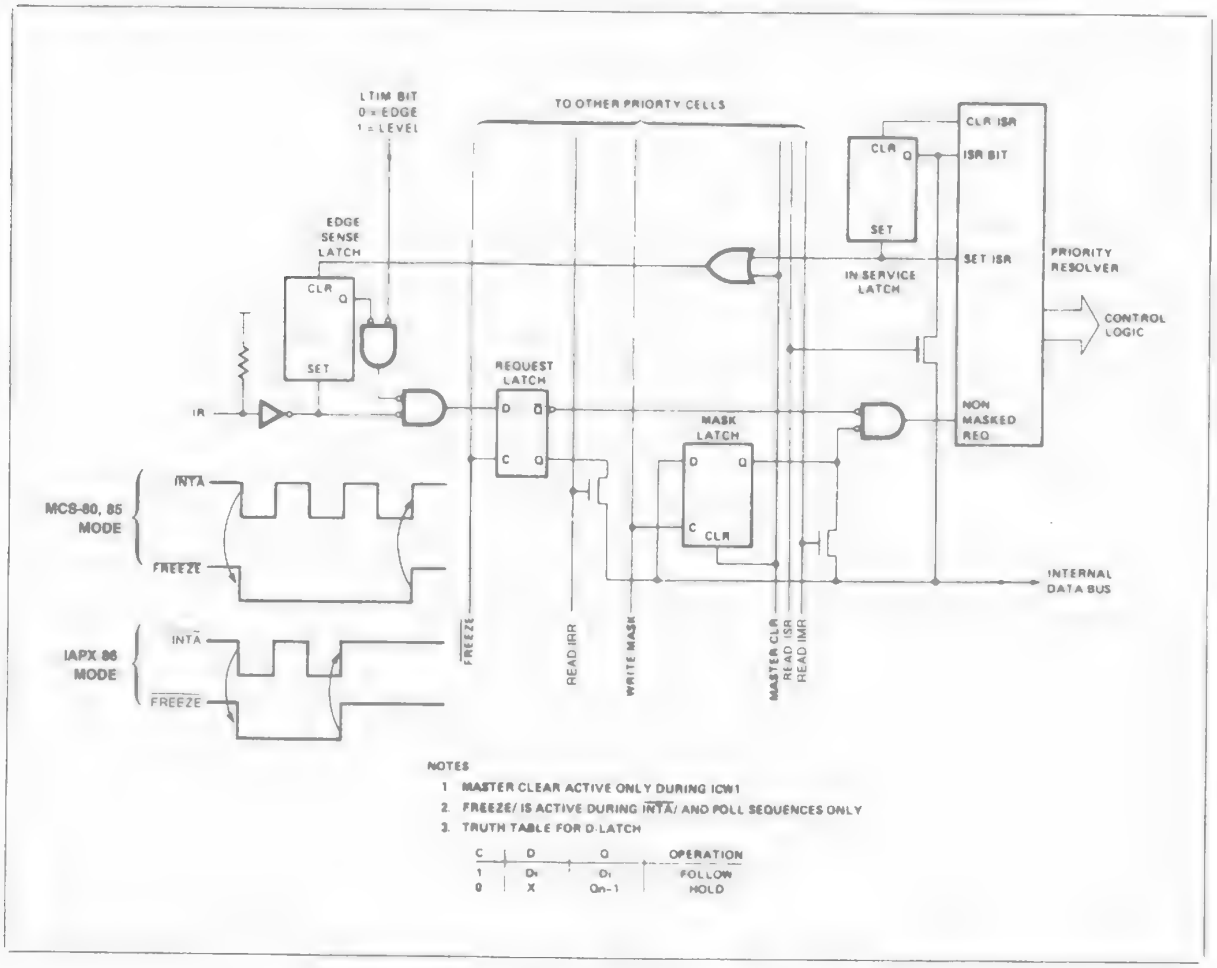

Figure 9. Priority Cell—Simplified Logic Diagram

READING THE 8259A STATUS

The input status of several internal registers can be read to update the user information on the system. The following registers can be read via OCW3 (IRR and ISR or OCW1 [IMR]).

Interrupt Request Register (IRR): 8-bit register which contains the levels requesting an interrupt to be acknowledged. The highest request level is reset from the IRR when an interrupt is acknowledged. (Not affected by IMR.)

In-Service Register (ISR): 8-bit register which contains the priority levels that are being serviced. The ISR is updated when an End of Interrupt Command is issued.

Interrupt Mask Register: 8-bit register which contains the interrupt request lines which are masked.

The IRR can be read when, prior to the RD pulse, a Read Register Command is issued with OCW3 (RR = 1, RIS = 0.)

The ISR can be read when, prior to the RD pulse, a Read Register Command is issued with OCW3 (RR = 1, RIS = 1).

There is no need to write an OCW3 before every status read operation, as long as the status read corresponds with the previous one; i.e., the 8259A "remembers" whether the IRR or ISR has been previously selected by the OCW3. This is not true when poll is used.

After initialization the 8259A is set to IRR.

For reading the IMR, no OCW3 is needed. The output data bus will contain the IMR whenever $\overline{RD}$ is active and AO = 1 (OCW1).

Polling overrides status read when P = 1, RR = 1 in OCW3.

EDGE AND LEVEL TRIGGERED MODES

This mode is programmed using bit 3 in ICW1.

If LTIM = '0', an interrupt request will be recognized by a low to high transition on an IR input. The IR input can remain high without generating another interrupt.

If LTIM = '1', an interrupt request will be recognized by a 'high' level on IR Input, and there is no need for an edge detection. The interrupt request must be removed before the EOI command is issued or the CPU interrupt is enabled to prevent a second interrupt from occurring.

The priority cell diagram shows a conceptual circuit of the level sensitive and edge sensitive input circuitry of the 8259A. Be sure to note that the request latch is a transparent D type latch.

In both the edge and level triggered modes the IR inputs must remain high until after the falling edge of the first INTA. If the IR input goes low before this time a DEFAULT IR7 will occur when the CPU acknowledges the interrupt. This can be a useful safeguard for detecting interrupts caused by spurious noise glitches on the IR inputs. To implement this feature the IR7 routine is used for "clean up" simply executing a return instruction, thus ignoring the interrupt. If IR7 is needed for other purposes a default IR7 can still be detected by reading the ISR. A normal IR7 interrupt will set the corresponding ISR bit, a default IR7 won't. If a default IR7 routine occurs during a normal IR7 routine, however, the ISR will remain set. In this case it is necessary to keep track of whether or not the IR7 routine was previously entered. If another IR7 occurs it is a default.

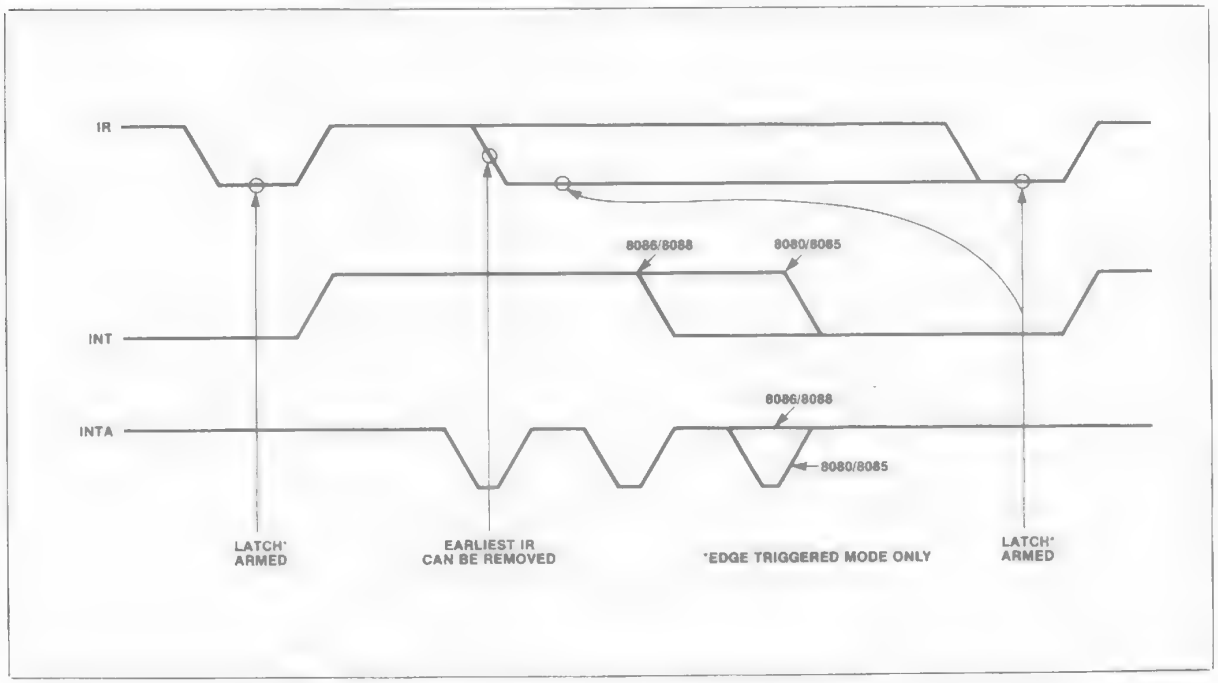

Figure 10. IR Triggering Timing Requirements

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THE SPECIAL FULLY NESTED MODE

This mode will be used in the case of a big system where cascading is used, and the priority has to be conserved within each slave. In this case the fully nested mode will be programmed to the master (using ICW4). This mode is similar to the normal nested mode with the following exceptions:

a. When an interrupt request from a certain slave is in service this slave is not locked out from the master's priority logic and further interrupt requests from higher priority IR's within the slave will be recognized by the master and will initiate interrupts to the processor. (In the normal nested mode a slave is masked out when its request is in service and no higher requests from the same slave can be serviced.)

b. When exiting the Interrupt Service routine the software has to check whether the interrupt serviced was the only one from that slave. This is done by sending a non-specific End of Interrupt (EOI) command to the slave and then reading its In-Service register and checking for zero. If it is empty, a non-specific EOI can be sent to the master too. If not, no EOI should be sent.

BUFFERED MODE

When the 8259A is used in a large system where bus driving buffers are required on the data bus and the cascading mode is used, there exists the problem of enabling buffers.

The buffered mode will structure the 8259A to send an enable signal on $\overline{SP}/\overline{EN}$ to enable the buffers. In this mode, whenever the 8259A's data bus outputs are enabled, the $\overline{SP}/\overline{EN}$ output becomes active.

This modification forces the use of software programming to determine whether the 8259A is a master or a slave. Bit 3 in ICW4 programs the buffered mode, and bit 2 in ICW4 determines whether it is a master or a slave.

CASCADE MODE

The 8259A can be easily interconnected in a system of one master with up to eight slaves to handle up to 64 priority levels.

The master controls the slaves through the 3 line cascade bus. The cascade bus acts like chip selects to the slaves during the $\overline{INTA}$ sequence.

In a cascade configuration, the slave interrupt outputs are connected to the master interrupt request inputs. When a slave request line is activated and afterwards acknowledged, the master will enable the corresponding slave to release the device routine address during bytes 2 and 3 of INTA. (Byte 2 only for 8086/8088).

The cascade bus lines are normally low and will contain the slave address code from the trailing edge of the first INTA pulse to the trailing edge of the third pulse. Each 8259A in the system must follow a separate initialization sequence and can be programmed to work in a different mode. An EOI command must be issued twice: once for the master and once for the corresponding slave. An address decoder is required to activate the Chip Select (CS) input of each 8259A.

The cascade lines of the Master 8259A are activated only for slave inputs, non slave inputs leave the cascade line inactive (low).

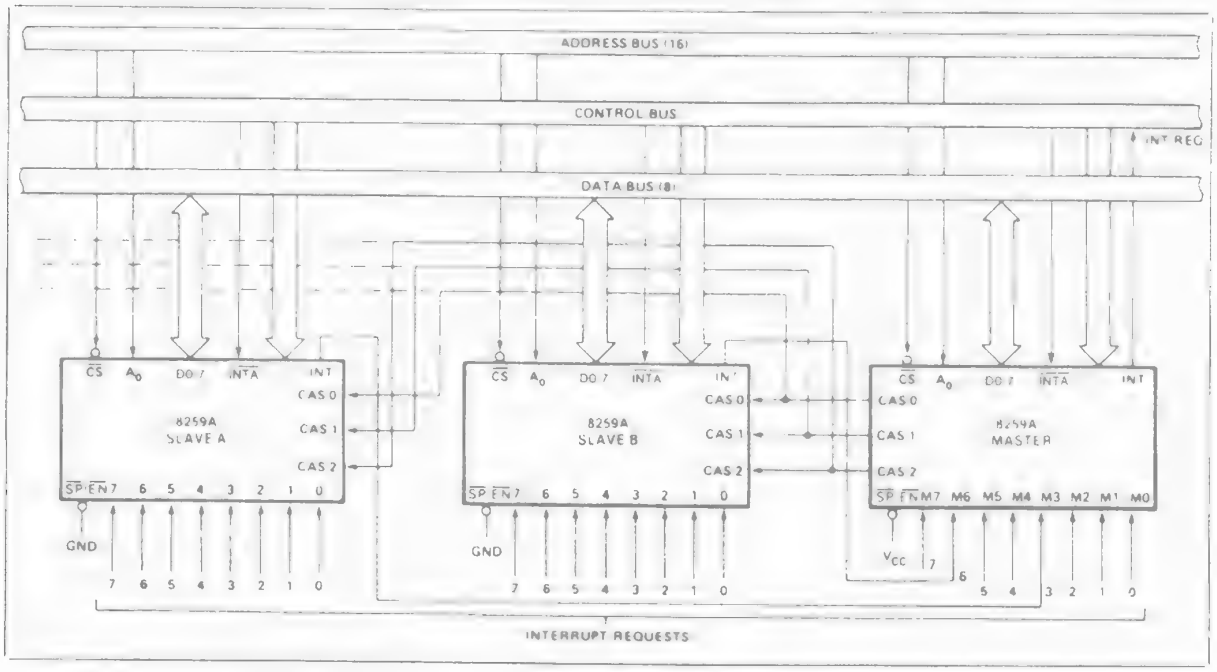


Figure 11. Cascading the 8259A

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage on Any Pin
with Respect to Ground ..... −0.5V to +7V
Power Dissipation ..... 1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.*

D.C. CHARACTERISTICS [T_A = 0°C to 70°C, V_{CC} = 5V ±5% (8259A-8), V_{CC} = 5V ±10% (8259A, 8259A-2)]

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	0.8	V	
V_{IH}	Input High Voltage	2.0*	V_{CC} +0.5V	V	
V_{OL}	Output High Voltage		0.45	V	I_{OL} = 2.2mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400μA
$V_{OH(INT)}$	Interrupt Output High Voltage	3.5		V	I_{OH} = −100μA
		2.4		V	I_{OH} = −400μA
I_{LI}	Input Load Current	−10	+10	μA	$0V \leq V_{IN} \leq V_{CC}$
I_{LOL}	Output Leakage Current	−10	+10	μA	$0.45V \leq V_{OUT} \leq V_{CC}$
I_{CC}	V_{CC} Supply Current		85	mA	
I_{LIR}	IR Input Load Current		−300	μA	V_{IN} = 0
			10	μA	V_{IN} = V_{CC}

*Note: For Extended Temperature EXPRESS V_{IH} = 2.3V.

CAPACITANCE (T_A = 25°C; V_{CC} = GND = 0V)

Symbol	Parameter	Min.	Typ.	Max.	Unit	Test Conditions
C_{IN}	Input Capacitance			10	pF	fc = 1 MHZ
$C_{I/O}$	I/O Capacitance			20	pF	Unmeasured pins returned to V_{SS}

A.C. CHARACTERISTICS [T_A = 0°C to 70°C, V_{CC} = 5V ±5% (8259A-8), V_{CC} = 5V ± 10% (8259A, 8259A-2)]

TIMING REQUIREMENTS

Symbol	Parameter	8259A-8		8259A		8259A-2		Units	Test Conditions
		Min.	Max.	Min.	Max.	Min.	Max.		
TAHRL	AO/$\overline{CS}$ Setup to $\overline{RD}$/$\overline{INTA}$↓	50		0		0		ns	
TRHAX	AO/$\overline{CS}$ Hold after $\overline{RD}$/$\overline{INTA}$↑	5		0		0		ns	
TRLRH	$\overline{RD}$ Pulse Width	420		235		160		ns	
TAHWL	AO/$\overline{CS}$ Setup to $\overline{WR}$↓	50		0		0		ns	
TWHAX	AO/$\overline{CS}$ Hold after $\overline{WR}$↑	20		0		0		ns	
TWLWH	$\overline{WR}$ Pulse Width	400		290		190		ns	
TDVWH	Data Setup to $\overline{WR}$↑	300		240		160		ns	
TWHDX	Data Hold after $\overline{WR}$↑	40		0		0		ns	
TJLJH	Interrupt Request Width (Low)	100		100		100		ns	See Note 1
TCVIAL	Cascade Setup to Second or Third $\overline{INTA}$↓ (Slave Only)	55		55		40		ns	
TRHRL	End of $\overline{RD}$ to next $\overline{RD}$ End of $\overline{INTA}$ to next $\overline{INTA}$ within an $\overline{INTA}$ sequence only	160		160		160		ns	
TWHWL	End of $\overline{WR}$ to next $\overline{WR}$	190		190		190		ns	

A.C. CHARACTERISTICS (Continued)

Symbol	Parameter	8259A-8		8259A		8259A-2		Units	Test Conditions
		Min.	Max.	Min.	Max.	Min.	Max.		
*TCHCL	End of Command to next Command (Not same command type)	500		500		500		ns	
	End of $\overline{INTA}$ sequence to next $\overline{INTA}$ sequence.								

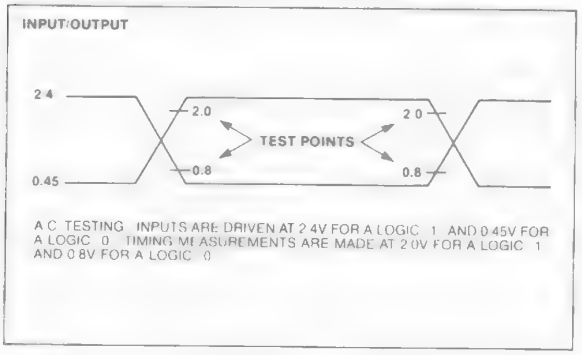
*Worst case timing for TCHCL in an actual microprocessor system is typically much greater than 500 ns (i.e. 8085A = 1.6μs, 8085A-2 = 1μs, 8086 = 1μs, 8086-2 = 625 ns)

NOTE: This is the low time required to clear the input latch in the edge triggered mode.

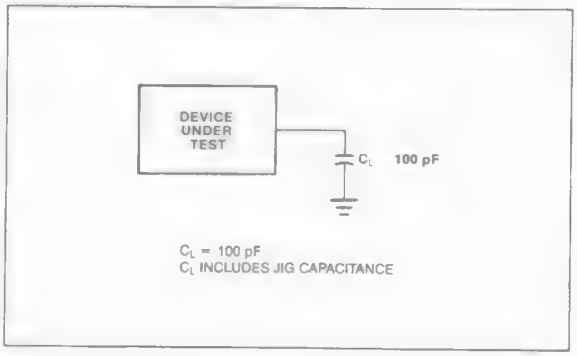
TIMING RESPONSES

Symbol	Parameter	8259A-8		8259A		8259A-2		Units	Test Conditions
		Min.	Max.	Min.	Max.	Min.	Max.		
TRLDV	Data Valid from $\overline{RD}$/$\overline{INTA}$↓		300		200		120	ns	C of Data Bus = 100 pF
TRHDZ	Data Float after $\overline{RD}$/$\overline{INTA}$↑	10	200	10	100	10	85	ns	C of Data Bus Max text C = 100 pF Min. test C = 15 pF
TJHIH	Interrupt Output Delay		400		350		300	ns	
TIALCV	Cascade Valid from First $\overline{INTA}$↓ (Master Only)		565		565		360	ns	C_{INT} = 100 pF
TRLEL	Enable Active from $\overline{RD}$↓ or $\overline{INTA}$↓		160		125		100	ns	$C_{CASCADE}$ = 100 pF
TRHEH	Enable Inactive from $\overline{RD}$↑ or $\overline{INTA}$↑		325		150		150	ns	
TAHDV	Data Valid from Stable Address		350		200		200	ns	
TCVDV	Cascade Valid to Valid Data		300		300		200	ns	

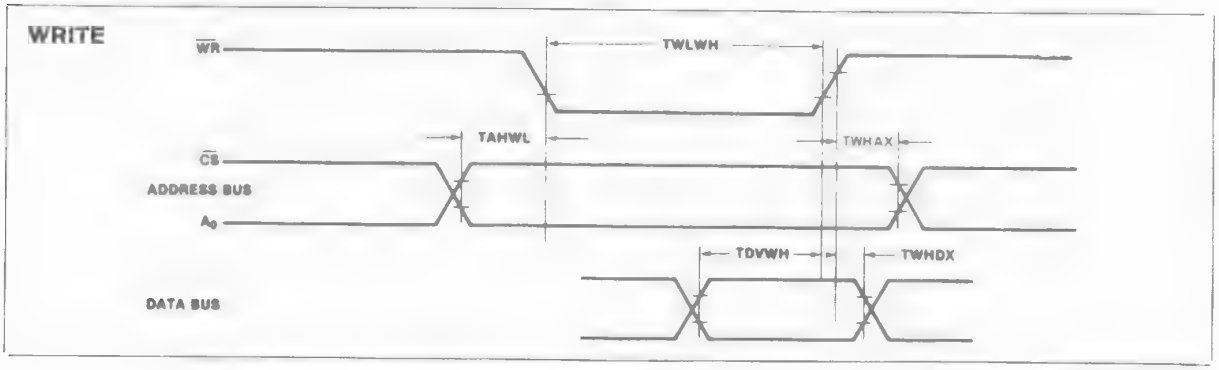
A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING LOAD CIRCUIT



WAVEFORMS



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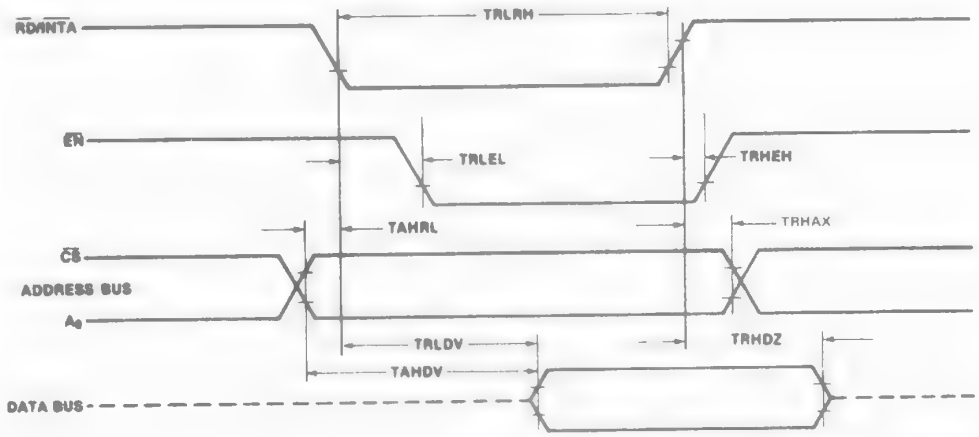
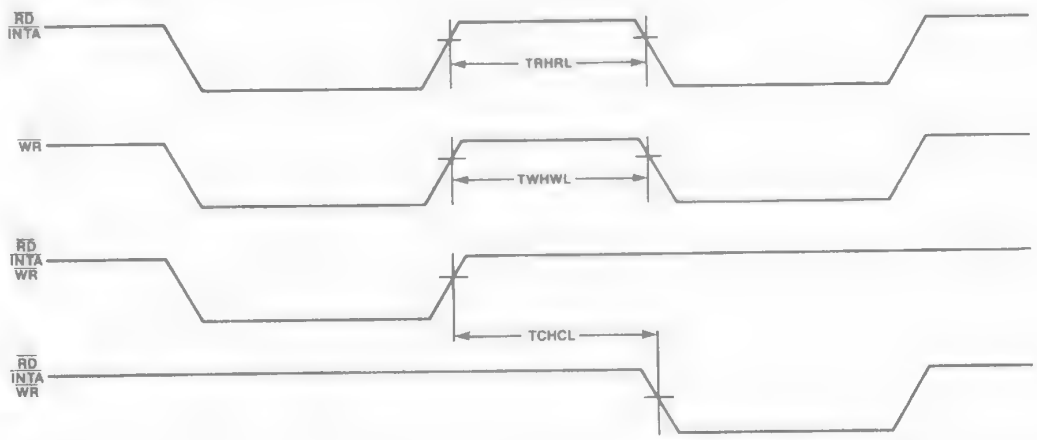
WAVEFORMS (Continued)

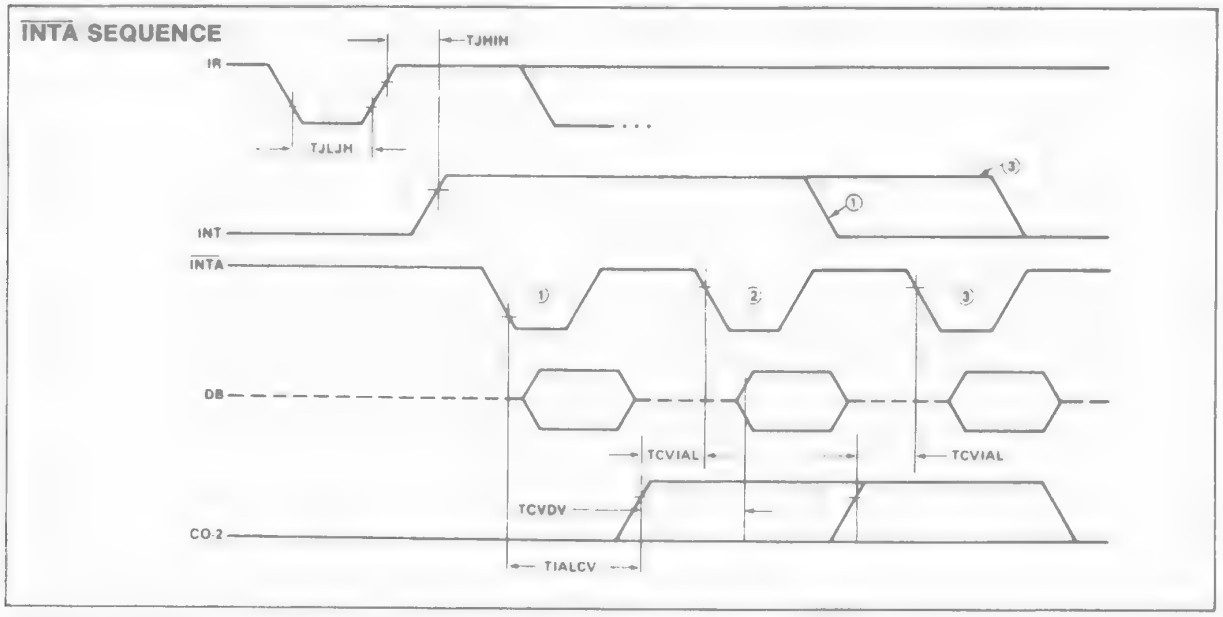
READ/INTA



OTHER TIMING



WAVEFORMS (Continued)



NOTES: Interrupt output must remain HIGH at least until leading edge of first INTA.
1. Cycle 1 in iAPX 86, iAPX 88 systems, the Data Bus is not active.

8355/8355-2
16,384-BIT ROM WITH I/O

- **2048 Words × 8 Bits**
- **Single +5V Power Supply**
- **Directly Compatible with 8085A and iAPX 88 Microprocessors**
- **2 General Purpose 8-Bit I/O Ports**
- **Each I/O Port Line Individually Programmable as Input or Output**
- **Multiplexed Address and Data Bus**
- **Internal Address Latch**
- **40-Pin DIP**

The Intel® 8355 is a ROM and I/O chip to be used in the 8085A and iAPX 88 microprocessor systems. The ROM portion is organized as 2048 words by 8 bits. It has a maximum access time of 450 ns to permit use with no wait states in the 8085A CPU.

The I/O portion consists of 2 general purpose I/O ports. Each I/O port has 8 lines and each I/O port line is individually programmable as input or output.

The 8355-2 has a 300 ns access time for compatibility with the 8085A-2 and 5 MHz iAPX 88 microprocessors.

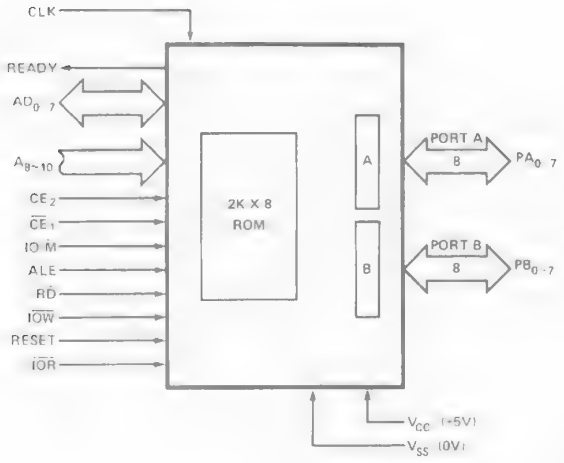
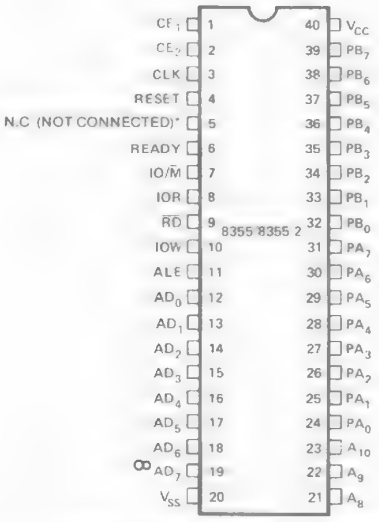


Figure 1. Block Diagram



*For 8755A compatibility, pin 5 should be directly tied to VCC.

Figure 2. Pin Configuration

Table 1. Pin Description

Symbol	Type	Name and Function
ALE	I	**Address Latch Enable:** When high, AD_{0-7}, $IO/\overline{M}$, A_{8-10}, CE_2, and $\overline{CE_1}$ enter the address latches. The signals (AD, $I/O\overline{M}$, A_{8-10}, CE_2, $\overline{CE_1}$) are latched in at the trailing edge of ALE.
AD_{0-7}	I	**Address/Data Bus (Bidirectional):** The lower 8-bits of the ROM or I/O address are applied to the bus lines when ALE is high. During an I/O cycle, Port A or B is selected based on the latched value of AD_0. If $\overline{RD}$ or $\overline{IOR}$ is low when the latched chip enables are active, the output buffers present data on the bus.
A_{8-10}	I	**Address Bus:** High order bits of the ROM address. They do not affect I/O operations.
$\overline{CE_1}$ CE_2	I	**Chip Enable Inputs:** $\overline{CE_1}$ is active low and CE_2 is active *high*. The 8355 can be accessed only when *BOTH* Chip Enables are active at the time the ALE signal latches them up. If either Chip Enable input is not active, the AD_{0-7} and READY outputs will be in a high impedance state.
$IO/\overline{M}$	I	**I/O Memory:** If the latched $IO/\overline{M}$ is high when $\overline{RD}$ is low, the output data comes from an I/O port. If it is low, the output data comes from the ROM.
$\overline{RD}$	I	**Read:** If the latched Chip Enables are active when $\overline{RD}$ goes low, the AD_{0-7} output buffers are enabled and output either the selected ROM location or I/O port. When both $\overline{RD}$ and $\overline{IOR}$ are high, the AD_{0-7} output buffers are 3-stated.
$\overline{IOW}$	I	**I/O Write:** If the latched Chip Enables are active, a low on $\overline{IOW}$ causes the output port pointed to by the latched value of AD_0 to be written with the data on AD_{0-7}. The state of $IO/\overline{M}$ is ignored.
CLK	I	**Clock:** Used to force the READY into its high impedance state after it has been forced low by $\overline{CE_1}$ low, CE_2 high and ALE high.
READY	O	**READY:** A 3-state output controlled by $\overline{CE_1}$, CE_2, ALE and CLK. READY is forced low when the Chip Enables are active during the time ALE is high, and remains low until the rising edge of the next CLK.
PA_{0-7}	I/O	**Port A:** General purpose I/O pins. Their input/output direction is determined by the contents of Data Direction Register (DDR). Port A is selected for write operations when the Chip Enables are active and $\overline{IOW}$ is low and a 0 was previously latched from AD_0, AD_1. Read operation is selected by either $\overline{IOR}$ low and active Chip Enables and AD_0 and AD_1 low, *or* $IO/\overline{M}$ high, $\overline{RD}$ low, active chip enables, and AD_0 and AD_1, LOW.
PB_{0-7}	I/O	**Port B:** This general purpose I/O port is identical to Port A except that it is selected by a 1 latched from AD_0 and a 0 from AD_1.
RESET	I	**Reset:** An input high causes all pins in Port A and B to assume input mode. (Clear DER Register).
$\overline{IOR}$	I	**I/O Read:** When the Chip Enables are active, a low on $\overline{IOR}$ will output the selected I/O port onto the AD bus. $\overline{IOR}$ low performs the same function as the combination $IO/\overline{M}$ high and $\overline{RD}$ low. When $\overline{IOR}$ is not used in a system, $\overline{IOR}$ should be tied to V_{CC} ("1").
V_{CC}		**Voltage:** +5 volt supply.
V_{SS}		**Ground:** Ground Reference.

FUNCTIONAL DESCRIPTION

ROM Section

The 8355 contains an 8-bit address latch which allows it to interface directly to MCS-48, MCS-85, and iAPX 88/10 Microcomputers without additional hardware.

The ROM section of the chip is addressed by an 11-bit address and the Chip Enables. The address and levels on the Chip Enable pins are latched into the address latches on the falling edge of ALE. If the latched Chip Enables are active and IO/$\overline{M}$ is low when $\overline{RD}$ goes low, the contents of the ROM location addressed by the latched address are put out through AD_{0-7} output buffers.

I/O Section

The I/O section of the chip is addressed by the latched value of AD_{0-1}. Two 8-bit Data Direction Registers (DDR) in 8355 determine the input/output status of each pin in the corresponding ports. A "0" in a particular bit position of a DDR signifies that the corresponding I/O port bit is in the input mode. A "1" in a particular bit position signifies that the corresponding I/O port bit is in the output mode. In this manner the I/O ports of the 8355 are bit-by-bit programmable as inputs or outputs. The table summarizes port and DDR designation. DDR's cannot be read.

AD_1	AD_0	Selection
0	0	Port A
0	1	Port B
1	0	Port A Data Direction Register (DDR A)
1	1	Port B Data Direction Register (DDR B)

When $\overline{IOW}$ goes low and the Chip Enables are active, the data on the AD_{0-7} is written into I/O port selected by the latched value of AD_{0-1}. During this operation all I/O bits of the selected port are affected, regardless of their I/O mode and the state of IO/$\overline{M}$. The actual output level does not change until $\overline{IOW}$ returns high (glitch free output).

A port can be read out when the latched Chip Enables are active and either $\overline{RD}$ goes low with IO/$\overline{M}$ high, or $\overline{IOR}$ goes low. Both input and output mode bits of a selected port will appear on lines AD_{0-7}.

To clarify the function of the I/O ports and Data Direction Registers, the following diagram shows the configuration of one bit of PORT A and DDR A. The same logic applies to PORT B and DDR B.

Note that hardware RESET or writing a zero to the DDR latch will cause the output latch's output buffer to be disabled, preventing the data in the output latch from being passed through to the pin. This is equivalent to putting the port in the input mode. Note also that the data can be written to the Output Latch even though the Output Buffer has been disabled. This enables a port to be initialized with a value prior to enabling the output.

The diagram also shows that the contents of PORT A and PORT B can be read even when the ports are configured as outputs.

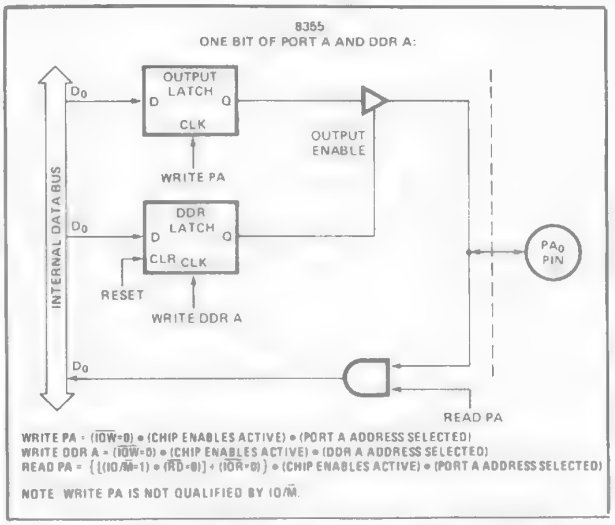


Figure 3. 8355 One Bit of Port A and DDR A

SYSTEM APPLICATIONS

System Interface with 8085A and iAPX 88

A system using the 8355 can use either one of the two I/O interface techniques:

- Standard I/O
- Memory Mapped I/O

If a standard I/O technique is used, the system can use the feature of both CE_2 and $\overline{CE}_1$. By using a combination of unused address lines A_{11-15} and the Chip Enable inputs, the system can use up to 5 each 8355's without requiring a CE decoder. See Figure 5a and 5b.

If a memory mapped I/O approach is used the 8355 will be selected by the combination of both the Chip Enables and IO/$\overline{M}$ using AD_{8-15} address lines. See Figure 4.

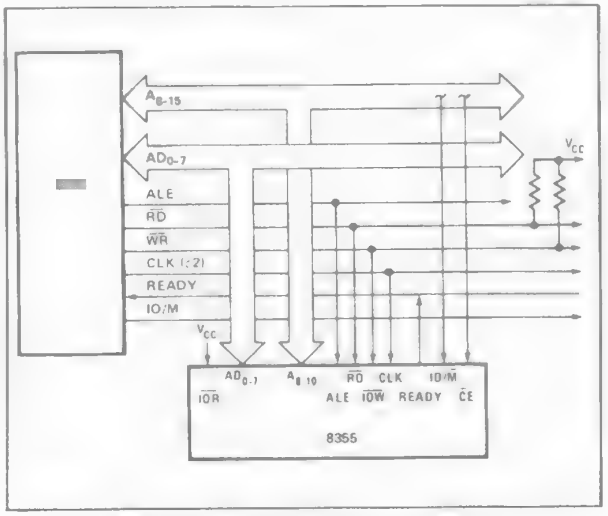


Figure 4. 8355 in 8085A System (Memory-Mapped I/O)

iAPX 88 FIVE CHIP SYSTEM:

- 1.25 K Bytes RAM
- 2 K Bytes ROM
- 38 I/O Pins
- 1 Internal Timer
- 2 Interrupt Levels

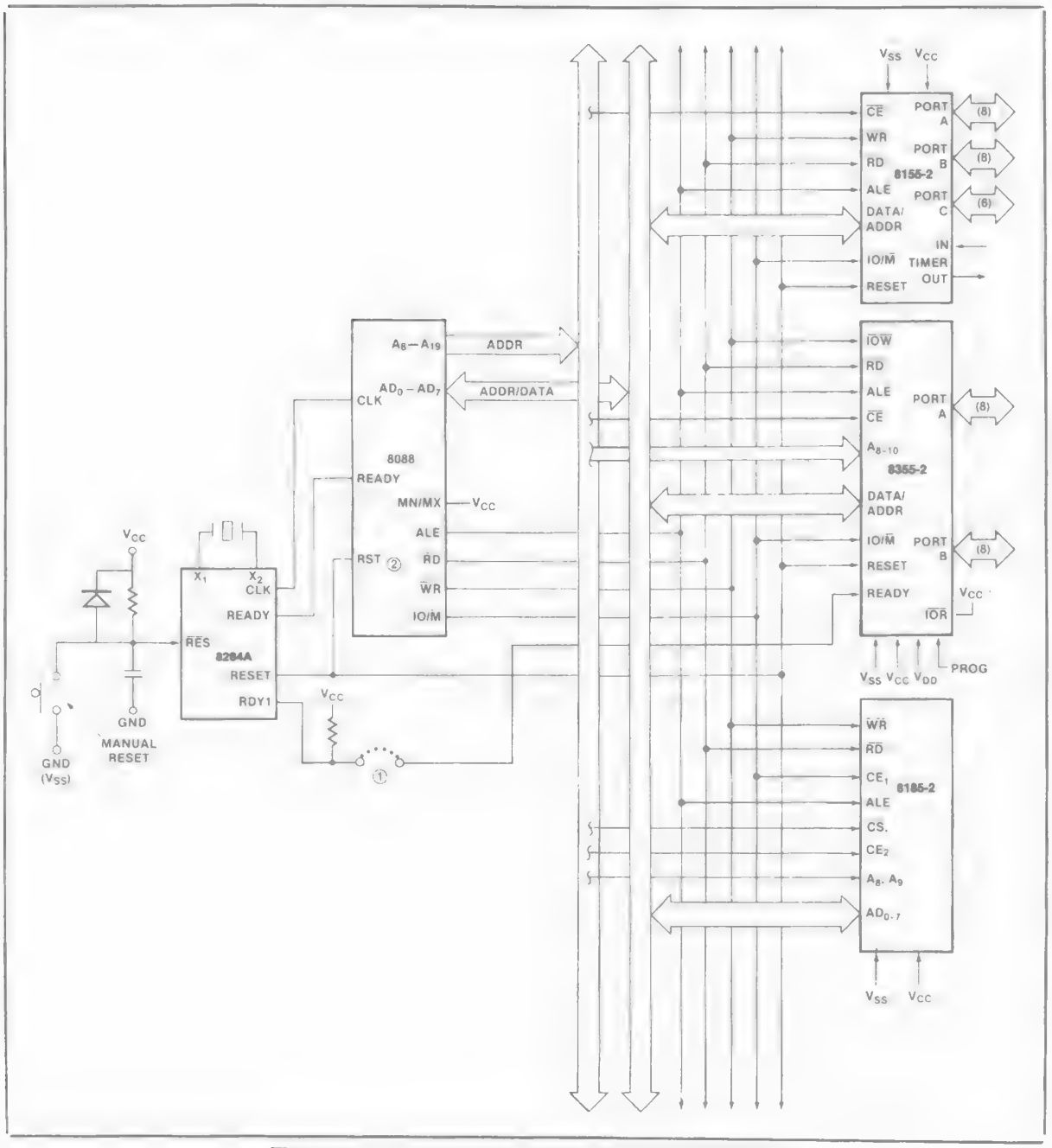


Figure 5a. iAPX 88 Five Chip System Configuration

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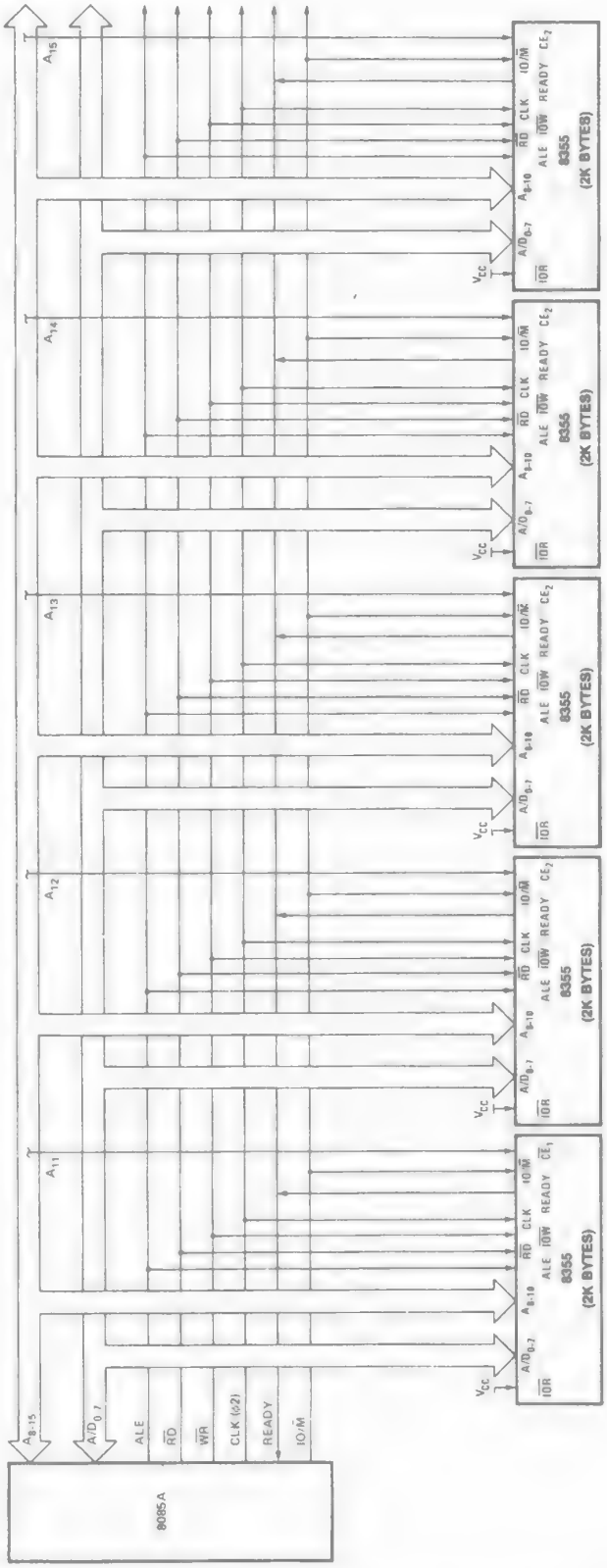


NOTE: Use $\overline{CE_1}$ for the first 8355 in the system, and CE_2 for the other 8355's. Permits up to 5-8355's in a system without CE decoder.

Figure 5b. 8355 in 8085A System (Standard I/O)

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... 0°C to +70°C
Storage Temperature ..... -65°C to +150°C
Voltage on Any Pin
With Respect to Ground ..... -0.5V to +7V
Power Dissipation 1.5W

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C; V_{CC} = 5V ± 5%)

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_{IL}	Input Low Voltage	-0.5	0.8	V	V_{CC} = 5.0V
V_{IH}	Input High Voltage	2.0	V_{CC}+0.5	V	V_{CC} = 5.0V
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = -400μA
I_{IL}	Input Leakage		10	μA	$0V \leq V_{IN} \leq V_{CC}$
I_{LO}	Output Leakage Current		±10	μA	$0.45V \leq V_{OUT} \leq V_{CC}$
I_{CC}	V_{CC} Supply Current		180	mA	

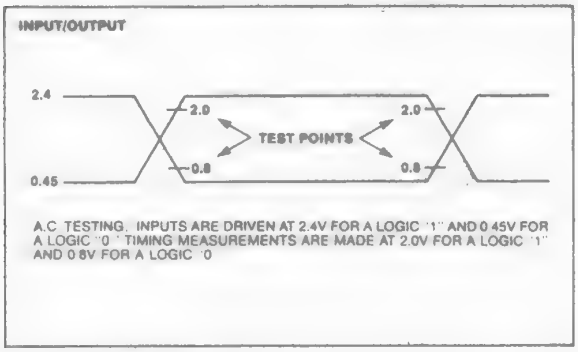
A.C. CHARACTERISTICS (T_A = 0°C to 70°C; V_{CC} = 5V ± 5%)

Symbol	Parameter	8355		8355-2		Units
		Min.	Max.	Min.	Max.	
t_{CYC}	Clock Cycle Time	320		200		ns
T_1	CLK Pulse Width	80		40		ns
T_2	CLK Pulse Width	120		70		ns
t_f, t_r	CLK Rise and Fall Time		30		30	ns
t_{AL}	Address to Latch Set Up Time	50		30		ns
t_{LA}	Address Hold Time after Latch	80		45		ns
t_{LC}	Latch to READ/WRITE Control	100		40		ns
t_{RD}	Valid Data Out Delay from READ Control*		170		140	ns
t_{AD}	Address Stable to Data Out Valid**		450		300	ns
t_{LL}	Latch Enable Width	100		70		ns
t_{RDF}	Data Bus Float after READ	0	100	0	85	ns
t_{CL}	READ/WRITE Control to Latch Enable	20		10		ns
t_{CC}	READ/WRITE Control Width	250		200		ns
t_{DW}	Data In to Write Set Up Time	150		150		ns
t_{WD}	Data In Hold Time After WRITE	30		10		ns
t_{WP}	WRITE to Port Output		400		300	ns
t_{PR}	Port Input Set Up Time	50		50		ns
t_{RP}	Port Input Hold Time	50		50		ns
t_{RYH}	READY HOLD Time	0	160	0	160	ns
t_{ARY}	ADDRESS (CE) to READY		160		160	ns
t_{RV}	Recovery Time Between Controls	300		200		ns
t_{RDE}	READ Control to Data Bus Enable	10		10		ns

*Or T_{AD}-(T_{AL} + T_{LC}), whichever is greater.

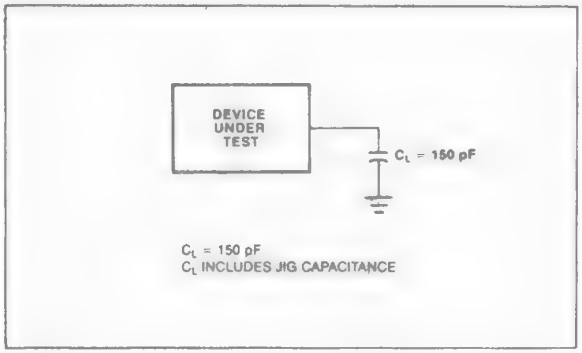
**Defines ALE to Data out Valid in conjunction with T_{AL}.

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING: INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0". TIMING MEASUREMENTS ARE MADE AT 2.0V FOR A LOGIC "1" AND 0.8V FOR A LOGIC "0".

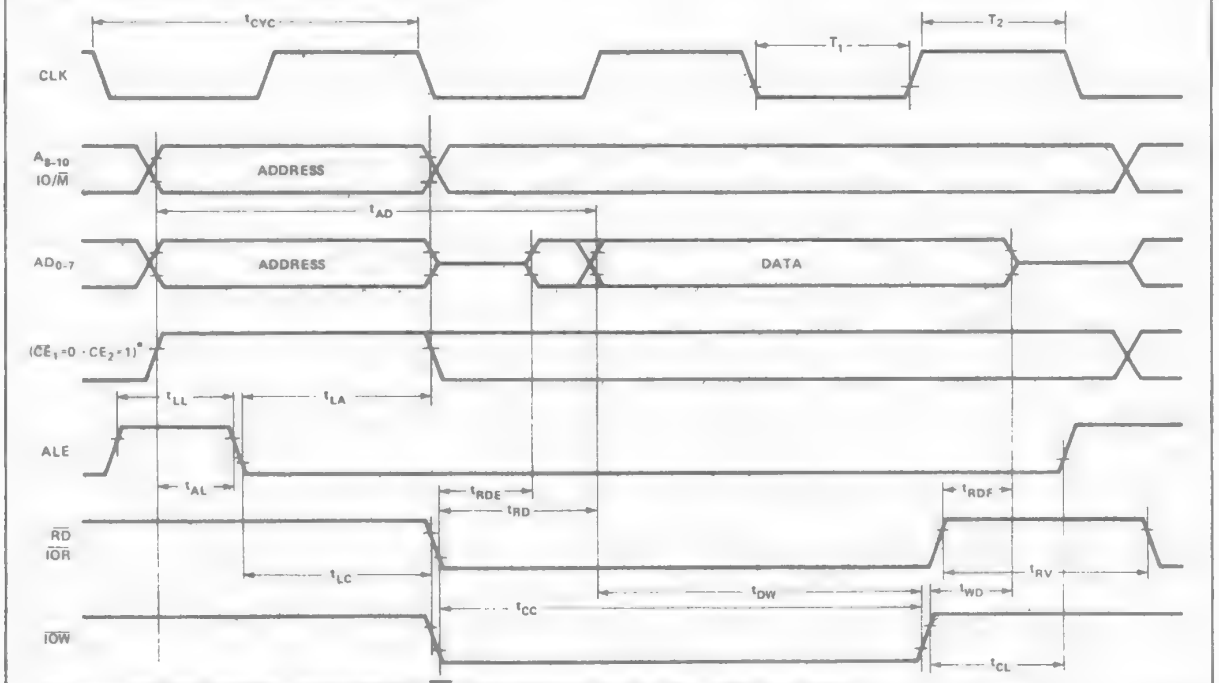
A.C. TESTING LOAD CIRCUIT



C_L = 150 pF
C_L INCLUDES JIG CAPACITANCE

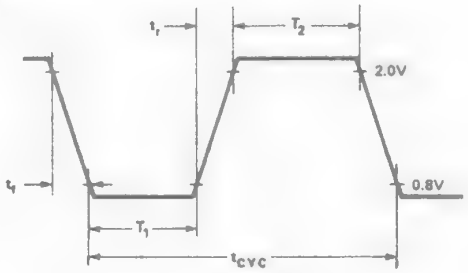
WAVEFORMS

ROM READ AND I/O READ AND WRITE



*Please note that for 8755A compatibility, $\overline{CE}_1$ should remain low for the entire read cycle.

8355 CLOCK SPECIFICATIONS



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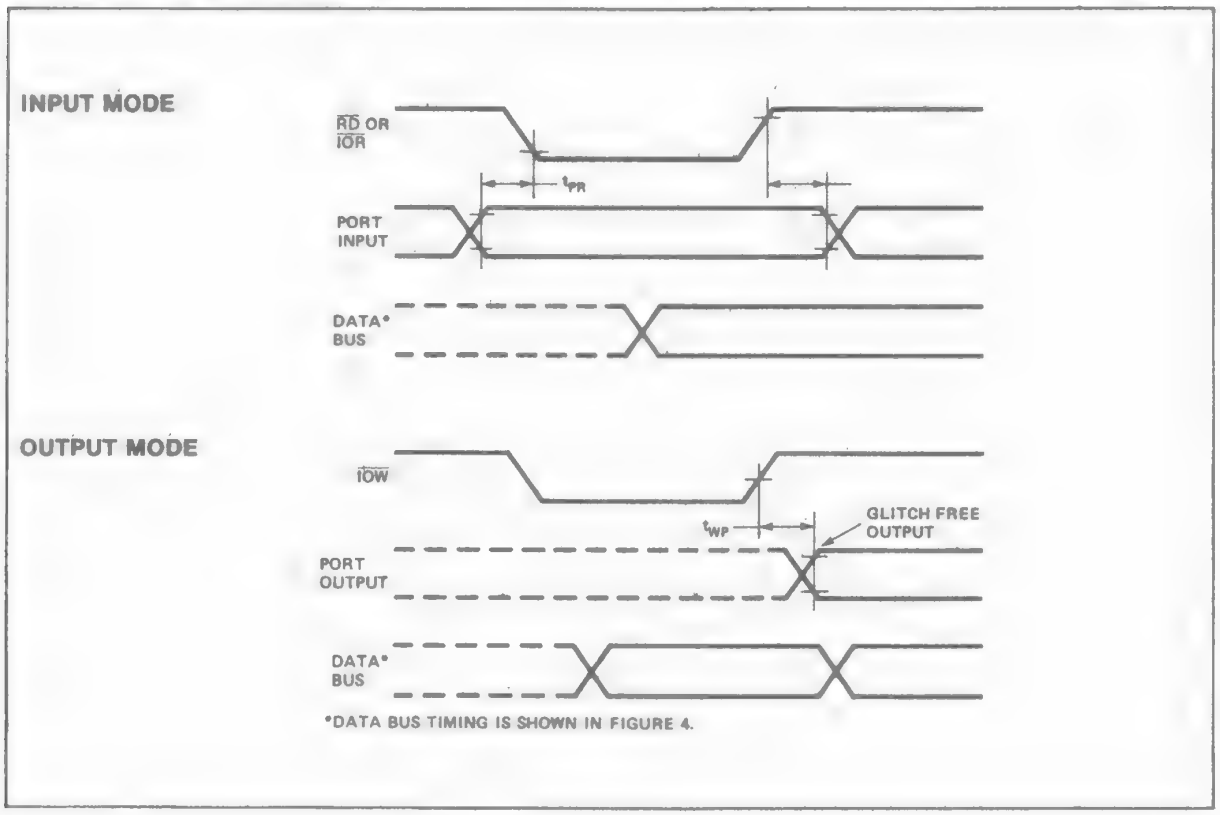
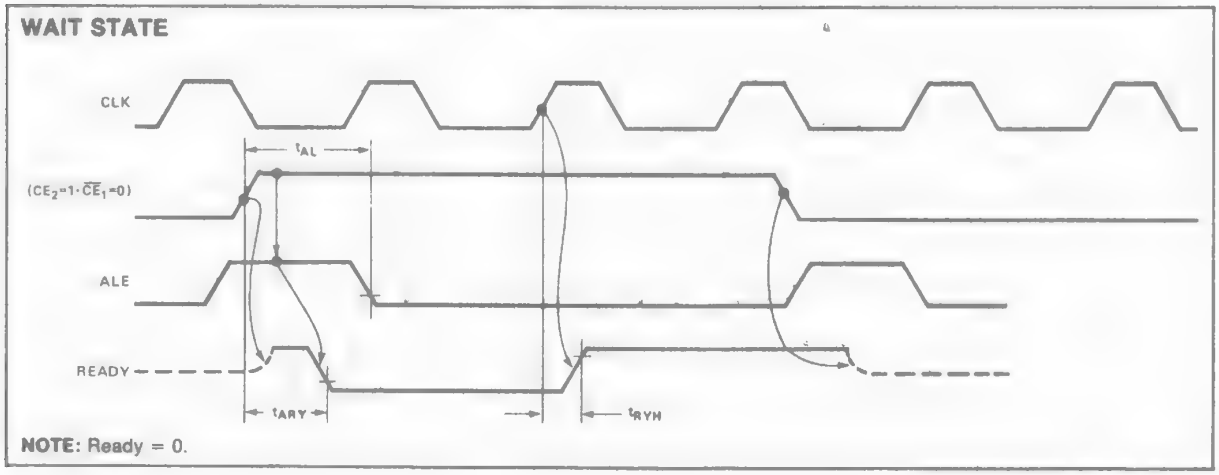
WAVEFORMS (Continued)





8755A/8755A-2
16,384-BIT EPROM WITH I/O

- 2048 Words × 8 Bits
- Single +5V Power Supply (V_{CC})
- Directly Compatible with 8085A and 8088 Microprocessors
- U.V. Erasable and Electrically Reprogrammable
- Internal Address Latch
- 2 General Purpose 8-Bit I/O Ports
- Each I/O Port Line Individually Programmable as Input or Output
- Multiplexed Address and Data Bus
- 40-Pin DIP
- Available in EXPRESS
  - Standard Temperature Range
  - Extended Temperature Range

The Intel® 8755A is an erasable and electrically reprogrammable ROM (EPROM) and I/O chip to be used in the 8085A and iAPX 88 microprocessor systems. The EPROM portion is organized as 2048 words by 8 bits. It has a maximum access time of 450 ns to permit use with no wait states in an 8085A CPU.

The I/O portion consists of 2 general purpose I/O ports. Each I/O port has 8 port lines, and each I/O port line is individually programmable as input or output.

The 8755A-2 is a high speed selected version of the 8755A compatible with the 5 MHz 8085A-2 and the 5 MHz iAPX 88 microprocessor.

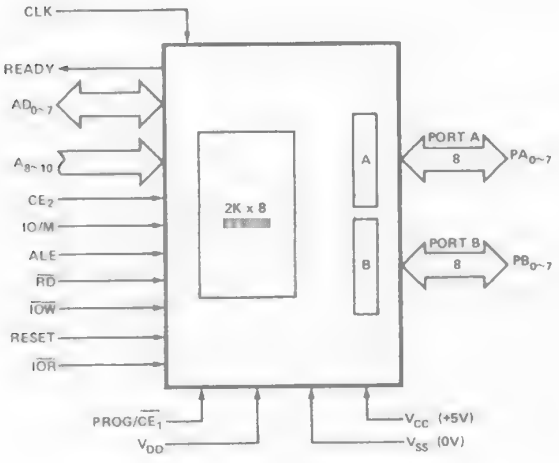


Figure 1. Block Diagram

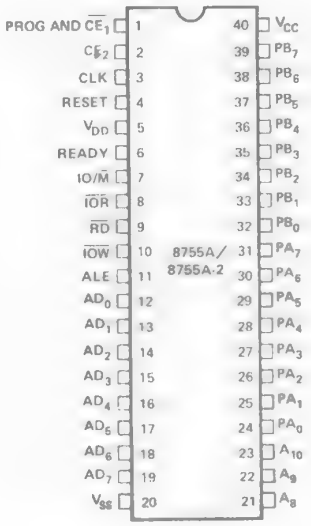


Figure 2. Pin Configuration

Intel Corporation Assumes No Responsibility for the Use of Any Circuitry Other Than Circuitry Embodied in an Intel Product. No Other Circuit Patent Licenses are Implied.
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Table 1. Pin Description

Symbol	Type	Name and Function
ALE	I	**Address Latch Enable:** When Address Latch Enable goes *high*, AD_{0-7}, $IO/\overline{M}$, A_{8-10}, CE_2, and $\overline{CE_1}$ enter the address latches. The signals (AD, $IO/\overline{M}$ AD_{8-10}, CE_2, $\overline{CE_1}$) are latched in at the trailing edge of ALE.
AD_{0-7}	I	**Bidirectional Address/Data Bus:** The lower 8-bits of the PROM or I/O address are applied to the bus lines when ALE is high. During an I/O cycle, Port A or B is selected based on the latched value of AD_0. IF $\overline{RD}$ or $\overline{IOR}$ is low when the latched Chip Enables are active, the output buffers present data on the bus.
A_{8-10}	I	**Address Bus:** These are the high order bits of the PROM address. They do not affect I/O operations.
PROG/$\overline{CE_1}$ CE_2	I	**Chip Enable Inputs:** $\overline{CE_1}$ is active low and CE_2 is active high. The 8755A can be accessed only when *both* Chip Enables are active at the time the ALE signal latches them up. If either Chip Enable input is not active, the AD_{0-7} and READY outputs will be in a high impedance state. $\overline{CE_1}$ is also used as a programming pin. (See section on programming.)
$IO/\overline{M}$	I	**I/O Memory:** If the latched $IO/\overline{M}$ is high when $\overline{RD}$ is low, the output data comes from an I/O port. If it is low the output data comes from the PROM.
$\overline{RD}$	I	**Read:** If the latched Chip Enables are active when $\overline{RD}$ goes low, the AD_{0-7} output buffers are enabled and output either the selected PROM location or I/O port. When both $\overline{RD}$ and $\overline{IOR}$ are high, the AD_{0-7} output buffers are 3-stated.
$\overline{IOW}$	I	**I/O Write:** If the latched Chip Enables are active, a low on $\overline{IOW}$ causes the output port pointed to by the latched value of AD_0 to be written with the data on AD_{0-7}. The state of $IO/\overline{M}$ is ignored.
CLK	I	**Clock:** The CLK is used to force the READY into its high impedance state after it has been forced low by $\overline{CE_1}$ low, CE_2 high, and ALE high.
READY	O	**Ready** is a 3-state output controlled by $\overline{CE_1}$, CE_2, ALE and CLK. READY is forced low when the Chip Enables are active during the time ALE is high, and remains low until the rising edge of the next CLK. (See Figure 6c.)
PA_{0-7}	I/O	**Port A:** These are general purpose I/O pins. Their input/output direction is determined by the contents of Data Direction Register (DDR). Port A is selected for write operations when the Chip Enables are active and $\overline{IOW}$ is low and a 0 was previously latched from AD_0, AD_1. Read Operation is selected by either $\overline{IOR}$ low and active Chip Enables and AD_0 and AD_1 low, *or* $IO/\overline{M}$ high, $\overline{RD}$ low, active Chip Enables, and AD_0 and AD_1 low.
PB_{0-7}	I/O	**Port B:** This general purpose I/O port is identical to Port A except that it is selected by a 1 latched from AD_0 and a 0 from AD_1.
RESET	I	**Reset:** In normal operation, an input high on RESET causes all pins in Ports A and B to assume input mode (clear DDR register).
$\overline{IOR}$	I	**I/O Read:** When the Chip Enables are active, a low on $\overline{IOR}$ will output the selected I/O port onto the AD bus. $\overline{IOR}$ low performs the same function as the combination of $IO/\overline{M}$ high and $\overline{RD}$ low. When $\overline{IOR}$ is not used in a system, $\overline{IOR}$ should be tied to V_{CC} ("1").
V_{CC}		**Power:** +5 volt supply.
V_{SS}		**Ground:** Reference.
V_{DD}		**Power Supply:** V_{DD} is a programming voltage, and must be tied to V_{CC} when the 8755A is being read. For programming, a high voltage is supplied with V_{DD} = 25V, typical. (See section on programming.)

FUNCTIONAL DESCRIPTION

PROM Section

The 8755A contains an 8-bit address latch which allows it to interface directly to MCS-48, MCS-85 and iAPX 88/10 Microcomputers without additional hardware.

The PROM section of the chip is addressed by the 11-bit address and the Chip Enables. The address, $\overline{CE}_1$ and CE_2 are latched into the address latches on the falling edge of ALE. If the latched Chip Enables are active and IO/$\overline{M}$ is low when $\overline{RD}$ goes low, the contents of the PROM location addressed by the latched address are put out on the AD_{0-7} lines (provided that V_{DD} is tied to V_{CC}.)

I/O Section

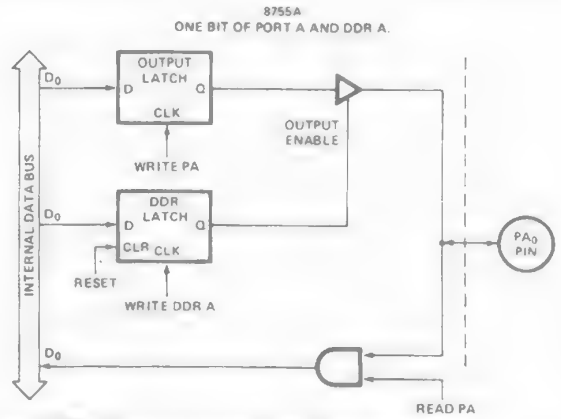
The I/O section of the chip is addressed by the latched value of AD_{0-1}. Two 8-bit Data Direction Registers (DDR) in 8755A determine the input/output status of each pin in the corresponding ports. A "0" in a particular bit position of a DDR signifies that the corresponding I/O port bit is in the input mode. A "1" in a particular bit position signifies that the corresponding I/O port bit is in the output mode. In this manner the I/O ports of the 8755A are bit-by-bit programmable as inputs or outputs. The table summarizes port and DDR designation. DDR's cannot be read.

AD_1	AD_0	Selection
0	0	Port A
0	1	Port B
1	0	Port A Data Direction Register (DDR A)
1	1	Port B Data Direction Register (DDR B)

When $\overline{IOW}$ goes low and the Chip Enables are active, the data on the AD_{0-7} is written into I/O port selected by the latched value of AD_{0-1}. During this operation all I/O bits of the selected port are affected, regardless of their I/O mode and the state of IO/$\overline{M}$. The actual output level does not change until $\overline{IOW}$ returns high. (glitch free output)

A port can be read out when the latched Chip Enables are active and either $\overline{RD}$ goes low with IO/$\overline{M}$ high, or $\overline{IOR}$ goes low. Both input and output mode bits of a selected port will appear on lines AD_{0-7}.

To clarify the function of the I/O Ports and Data Direction Registers, the following diagram shows the configuration of one bit of PORT A and DDR A. The same logic applies to PORT B and DDR B.



WRITE PA = ($\overline{IOW}$=0) • (CHIP ENABLES ACTIVE) • (PORT A ADDRESS SELECTED)
WRITE DDR A = ($\overline{IOW}$=0) • (CHIP ENABLES ACTIVE) • (DDR A ADDRESS SELECTED)
READ PA = {[(IO/$\overline{M}$=1) • ($\overline{RD}$=0)] + ($\overline{IOR}$=0)} • (CHIP ENABLES ACTIVE) • (PORT A ADDRESS SELECTED)

NOTE: WRITE PA IS NOT QUALIFIED BY IO/$\overline{M}$.

Note that hardware RESET or writing a zero to the DDR latch will cause the output latch's output buffer to be disabled, preventing the data in the Output Latch from being passed through to the pin. This is equivalent to putting the port in the input mode. Note also that the data can be written to the Output Latch even though the Output Buffer has been disabled. This enables a port to be initialized with a value prior to enabling the output.

The diagram also shows that the contents of PORT A and PORT B can be read even when the ports are configured as outputs.

TABLE 1. 8755A PROGRAMMING MODULE CROSS REFERENCE

MODULE NAME	USE WITH
UPP 955	UPP(4)
UPP UP2(2)	UPP 855
PROMPT 975	PROMPT 80/85(3)
PROMPT 475	PROMPT 48(1)

NOTES:
1. Described on p. 13-34 of 1978 Data Catalog.
2. Special adaptor socket.
3. Described on p. 13-39 of 1978 Data Catalog.
4. Described on p. 13-71 of 1978 Data Catalog.

ERASURE CHARACTERISTICS

The erasure characteristics of the 8755A are such that erasure begins to occur when exposed to light with wavelengths shorter than approximately 4000 Angstroms (Å). It should be noted that sunlight and certain types of fluorescent lamps have wavelengths in the 3000-4000Å range. Data show that constant exposure to room level fluorescent lighting could erase the typical 8755A in approximately 3 years while it would take approximately 1 week to cause erasure when exposed to direct sunlight. If the 8755A is to be exposed to these types of lighting conditions for extended periods of time, opaque labels are available from Intel which should be placed over the 8755 window to prevent unintentional erasure.

The recommended erasure procedure for the 8755A is exposure to shortwave ultraviolet light which has a wavelength of 2537 Angstroms (Å). The integrated dose (i.e., UV intensity X exposure time) for erasure should be a minimum of 15W-sec/cm^2. The erasure time with this dosage is approximately 15 to 20 minutes using an ultraviolet lamp with a 12000μW/cm^2 power rating. The 8755A should be placed within one inch from the lamp tubes during erasure. Some lamps have a filter on their tubes and this filter should be removed before erasure.

PROGRAMMING

Initially, and after each erasure, all bits of the EPROM portions of the 8755A are in the "1" state. Information is introduced by selectively programming "0" into the desired bit locations. A programmed "0" can only be changed to a "1" by UV erasure.

The 8755A can be programmed on the Intel® Universal PROM Programmer (UPP), and the PROMPT™ 80/85 and PROMPT-48™ design aids. The appropriate programming modules and adapters for use in programming both 8755A's and 8755's are shown in Table 1.

The program mode itself consists of programming a single address at a time, giving a single 50 msec pulse for every address. Generally, it is desirable to have a verify cycle after a program cycle for the same address as shown in the attached timing diagram. In the verify cycle (i.e., normal memory read cycle) 'V_{DD}' should be at +5V.

Preliminary timing diagrams and parameter values pertaining to the 8755A programming operation are contained in Figure 7.

SYSTEM APPLICATIONS

System Interface with 8085A and iAPX 88

A system using the 8755A can use either one of the two I/O Interface techniques:

- Standard I/O
- Memory Mapped I/O

If a standard I/O technique is used, the system can use the feature of both CE_2 and $\overline{CE_1}$. By using a combination of unused address lines A_{11-15} and the Chip Enable inputs, the 8085A system can use up to 5 each 8755A's without requiring a CE decoder. See Figure 4a and 4b.

If a memory mapped I/O approach is used the 8755A will be selected by the combination of both the Chip Enables and IO/$\overline{M}$ using AD_{8-15} address lines. See Figure 3.

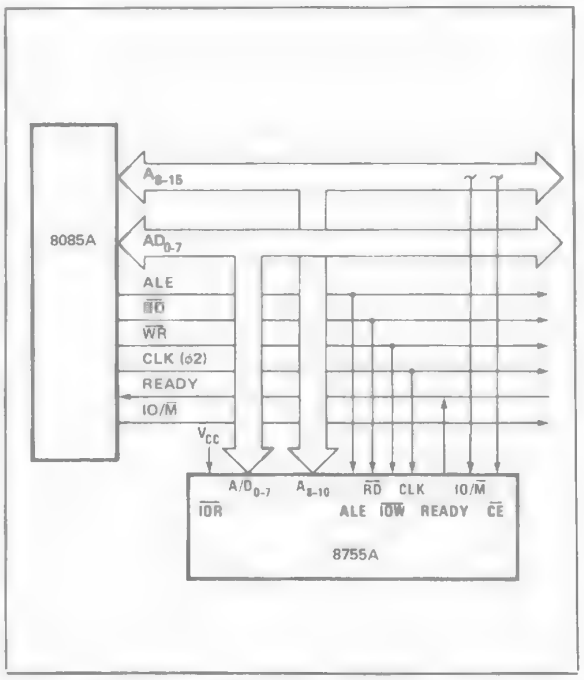


Figure 3. 8755A in 8085A System (Memory-Mapped I/O)

iAPX 88 FIVE CHIP SYSTEM

Figure 4 shows a five chip system containing:

- 1.25K Bytes RAM
- 2K Bytes ROM
- 38 I/O Pins
- 1 Interval Timer
- 2 Interrupt Levels

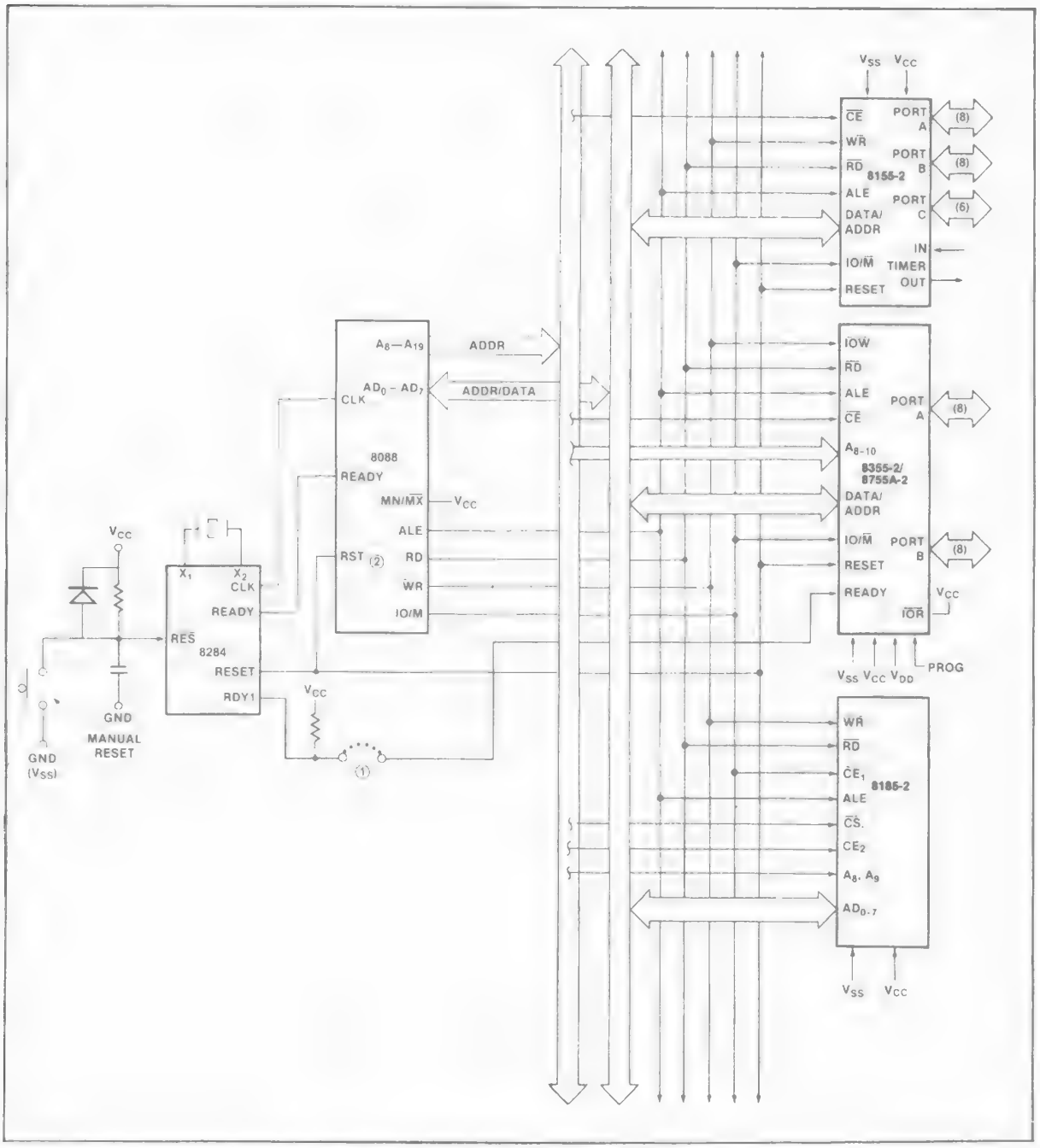
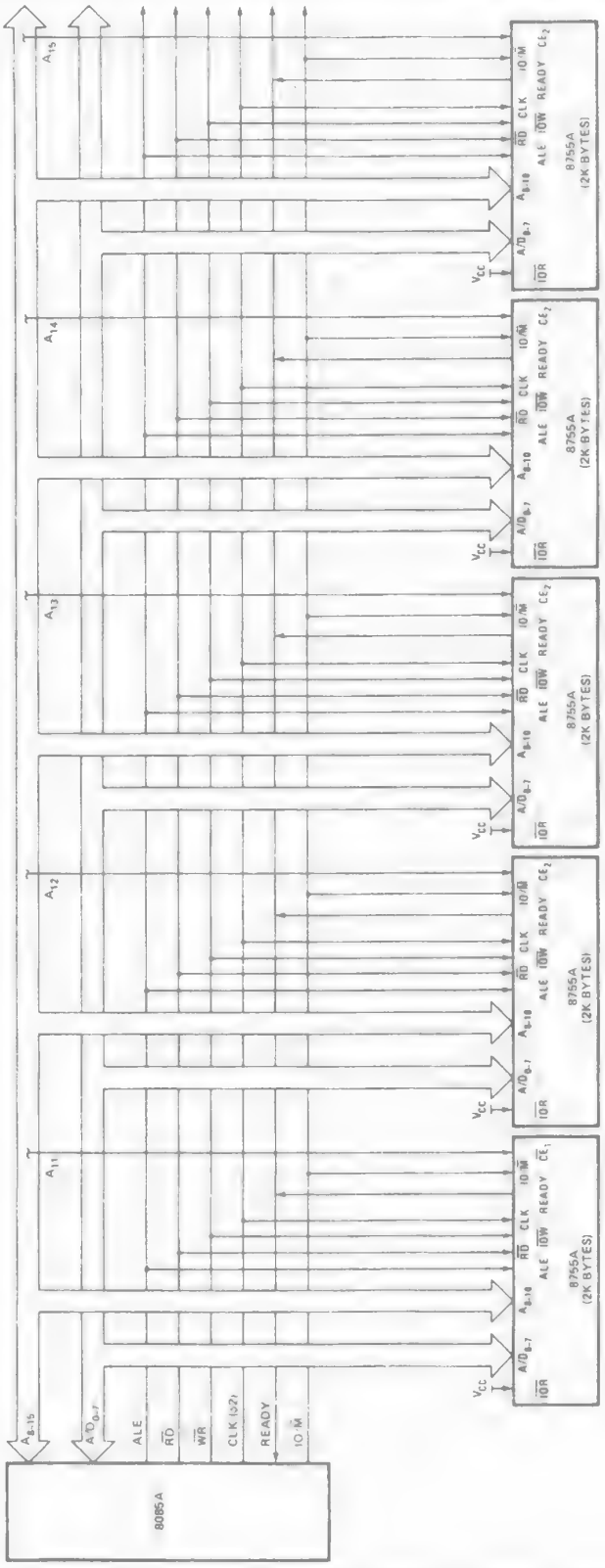


Figure 4a. iAPX 88 Five Chip System Configuration

AFN-00843C



Note: Use $\overline{CE}_1$ for the first 8755A in the system, and CE_2 for the other 8755A's. Permits up to 5-8755A's in a system without CE decoder.

Figure 4b. 8755A in 8085A System (Standard I/O)

AFN-00843D

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... 0°C to +70°C
Storage Temperature ..... -65°C to +150°C
Voltage on Any Pin
With Respect to Ground ..... -0.5V to +7V
Power Dissipation 1.5W

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS

(T_A = 0°C to 70°, V_{CC} = V_{DD} = 5V ± 5%; V_{CC} = V_{DD} = 5V ±10% for 8755A-2)

SYMBOL	PARAMETER	MIN.	MAX.	UNITS	TEST CONDITIONS
V_{IL}	Input Low Voltage	-0.5	0.8	V	V_{CC} = 5.0V
V_{IH}	Input High Voltage	2.0	V_{CC}+0.5	V	V_{CC} = 5.0V
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = -400μA
I_{IL}	Input Leakage		10	μA	$V_{SS} \leq V_{IN} \leq V_{CC}$
I_{LO}	Output Leakage Current		±10	μA	$0.45V \leq V_{OUT} \leq V_{CC}$
I_{CC}	V_{CC} Supply Current		180	mA	
I_{DD}	V_{DD} Supply Current		30	mA	V_{DD} = V_{CC}
C_{IN}	Capacitance of Input Buffer		10	pF	f_C = 1μHz
$C_{I/O}$	Capacitance of I/O Buffer		15	pF	f_C = 1μHz

D.C. CHARACTERISTICS — PROGRAMMING

(T_A = 0°C to 70°, V_{CC} = 5V ± 5%, V_{SS} = 0V, V_{DD} = 25V ±1V; V_{CC} = V_{DD} = 5V ±10% for 8755A-2)

Symbol	Parameter	Min.	Typ.	Max.	Unit
V_{DD}	Programming Voltage (during Write to EPROM)	24	25	26	V
I_{DD}	Prog Supply Current		15	30	mA

A.C. CHARACTERISTICS

(T_A = 0°C to 70°, V_{CC} = 5V ± 5%; V_{CC} = V_{DD} = 5V ±10% for 8755A-2)

Symbol	Parameter	8755A		8755A-2 (Preliminary)		Units
		Min.	Max.	Min.	Max.	
t_{CYC}	Clock Cycle Time	320		200		ns
T_1	CLK Pulse Width	80		40		ns
T_2	CLK Pulse Width	120		70		ns
t_f, t_r	CLK Rise and Fall Time		30		30	ns
t_{AL}	Address to Latch Set Up Time	50		30		ns
t_{LA}	Address Hold Time after Latch	80		45		ns
t_{LC}	Latch to READ/WRITE Control	100		40		ns
t_{RD}	Valid Data Out Delay from READ Control*		170		140	ns
t_{AD}	Address Stable to Data Out Valid**		450		300	ns
t_{LL}	Latch Enable Width	100		70		ns
t_{RDF}	Data Bus Float after READ	0	100	0	85	ns
t_{CL}	READ/WRITE Control to Latch Enable	20		10		ns
t_{CC}	READ/WRITE Control Width	250		200		ns
t_{DW}	Data In to Write Set Up Time	150		150		ns
t_{WD}	Data In Hold Time After WRITE	30		10		ns
t_{WP}	WRITE to Port Output		400		300	ns
t_{PR}	Port Input Set Up Time	50		50		ns
t_{RP}	Port Input Hold Time to Control	50		50		ns
t_{RYH}	READY HOLD Time to Control	0	160	0	160	ns
t_{ARY}	ADDRESS (CE) to READY		160		160	ns
t_{RV}	Recovery Time Between Controls	300		200		ns
t_{RDE}	READ Control to Data Bus Enable	10		10		ns

NOTE:

C_{LOAD} = 150pF.

*Or $T_{AD} - (T_{AL} + T_{LC})$, whichever is greater.

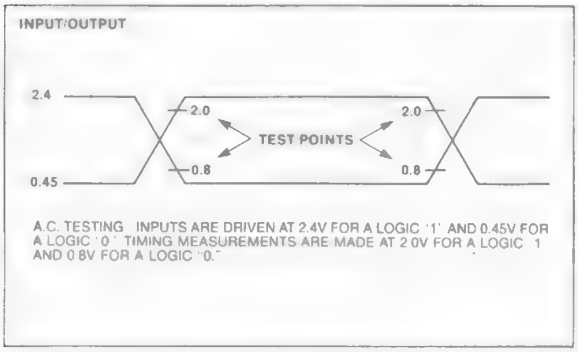
**Defines ALE to Data Out Valid in conjunction with T_{AL}.

A.C. CHARACTERISTICS — PROGRAMMING

(T_A = 0°C to 70°, V_{CC} = 5V ± 5%, V_{SS} = 0V, V_{DD} = 25V ±1V; V_{CC} = V_{DD} = 5V ±10% for 8755A-2)

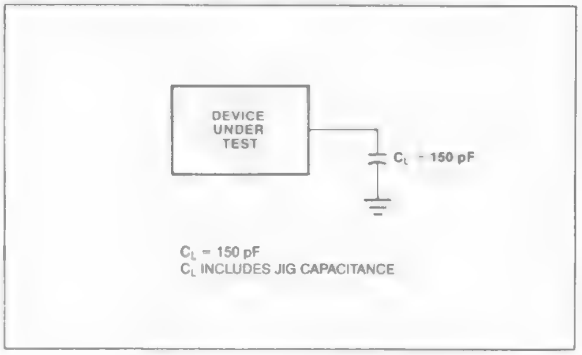
Symbol	Parameter	Min.	Typ.	Max.	Unit
t_{PS}	Data Setup Time	10			ns
t_{PD}	Data Hold Time	0			ns
t_S	Prog Pulse Setup Time	2			μs
t_H	Prog Pulse Hold Time	2			μs
t_{PR}	Prog Pulse Rise Time	0.01	2		μs
t_{PF}	Prog Pulse Fall Time	0.01	2		μs
t_{PRG}	Prog Pulse Width	45	50		msec

A.C. TESTING INPUT, OUTPUT WAVEFORM



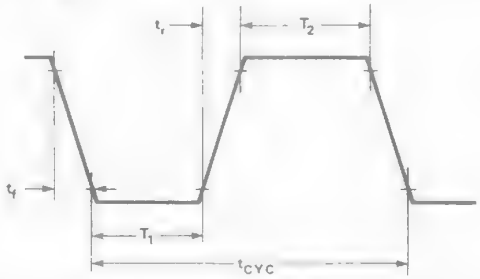
A.C. TESTING: INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0." TIMING MEASUREMENTS ARE MADE AT 2.0V FOR A LOGIC "1" AND 0.8V FOR A LOGIC "0."

A.C. TESTING LOAD CIRCUIT

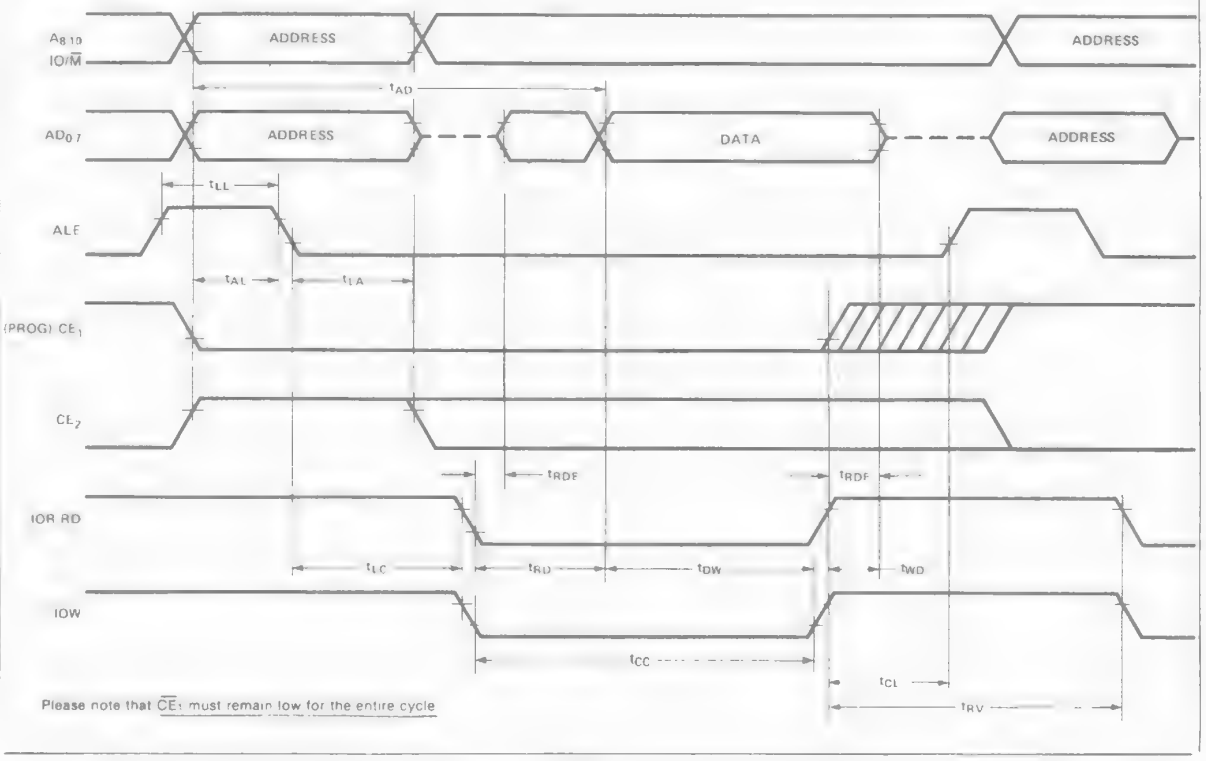


WAVEFORMS

CLOCK SPECIFICATION FOR 8755A

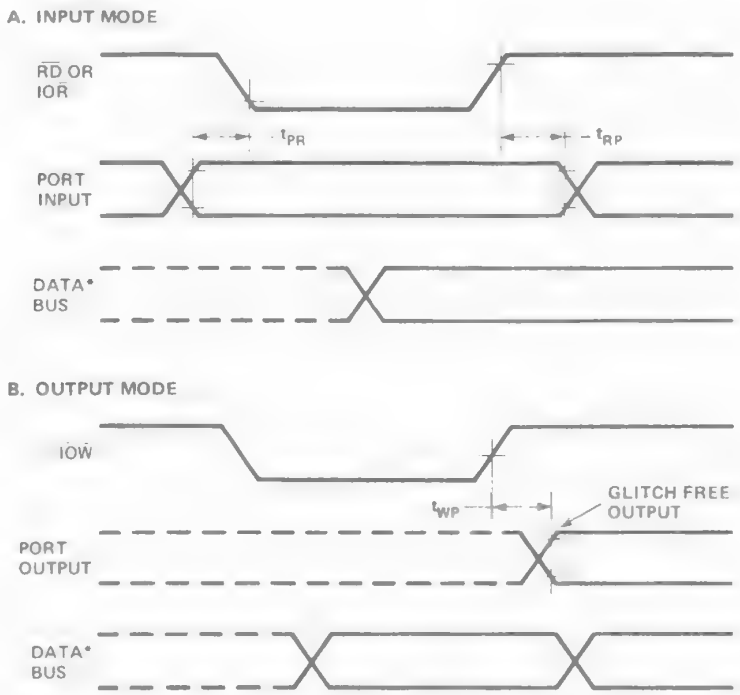


PROM READ, I/O READ AND WRITE

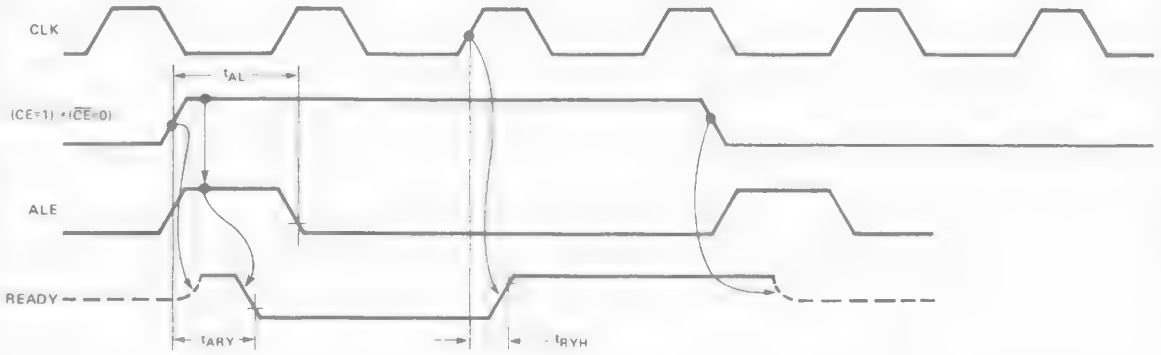


WAVEFORMS (Continued)

I/O PORT

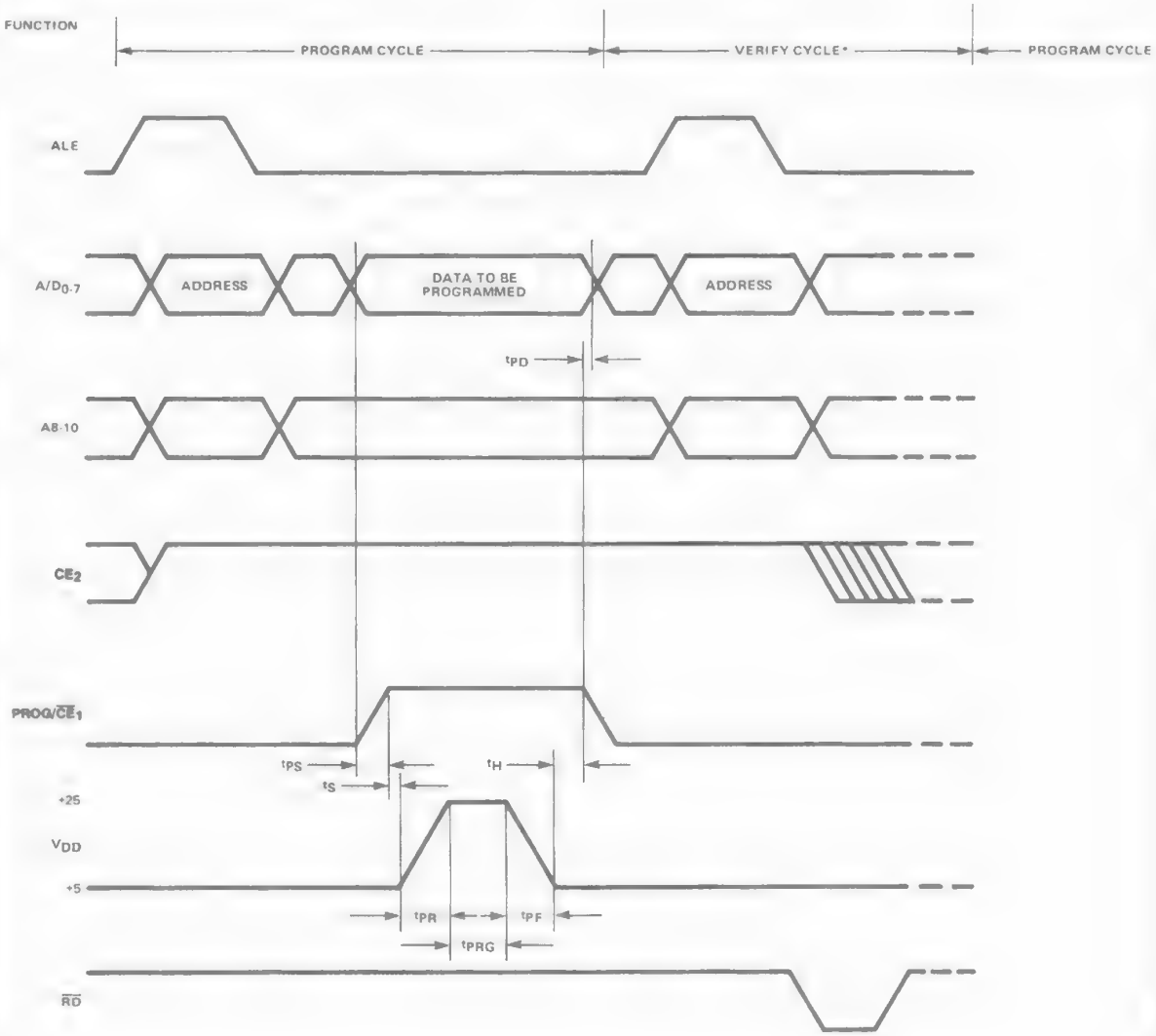


WAIT STATE (READY = 0)



WAVEFORMS (Continued)

8755A PROGRAM MODE



*VERIFY CYCLE IS A REGULAR MEMORY READ CYCLE (WITH V_{DD} = +5V FOR 8755A)

iAPX 86, 88, 186, 188 Microprocessors

3

iAPX 86/10
16-BIT HMOS MICROPROCESSOR

8086/8086-2/8086-1

- **Direct Addressing Capability 1 MByte of Memory**
- **Architecture Designed for Powerful Assembly Language and Efficient High Level Languages.**
- **14 Word, by 16-Bit Register Set with Symmetrical Operations**
- **24 Operand Addressing Modes**
- **Bit, Byte, Word, and Block Operations**
- **8 and 16-Bit Signed and Unsigned Arithmetic in Binary or Decimal Including Multiply and Divide**
- **Range of Clock Rates:**
  5 MHz for 8086,
  8 MHz for 8086-2,
  10 MHz for 8086-1
- **MULTIBUS™ System Compatible Interface**
- **Available in EXPRESS**
  - Standard Temperature Range
  - Extended Temperature Range

The Intel iAPX 86/10 high performance 16-bit CPU is available in three clock rates: 5, 8 and 10 MHz. The CPU is implemented in N-Channel, depletion load, silicon gate technology (HMOS), and packaged in a 40-pin CerDIP package. The iAPX 86/10 operates in both single processor and multiple processor configurations to achieve high performance levels.

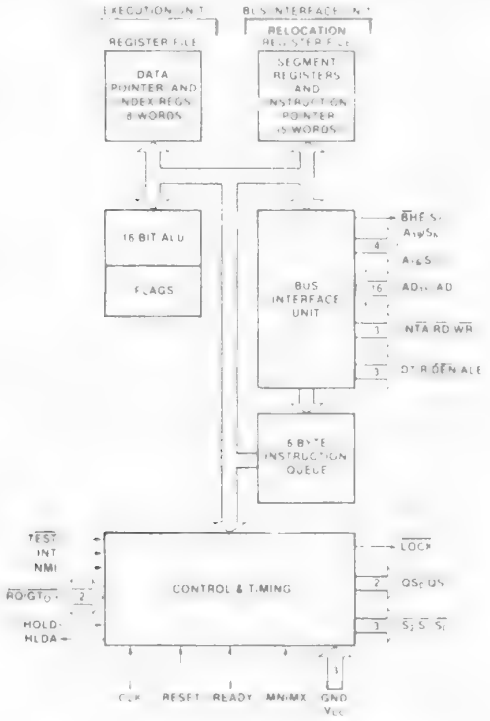
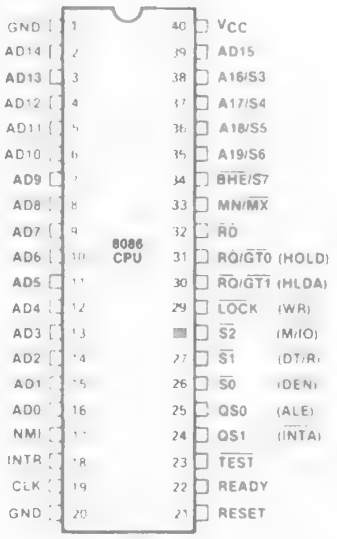


Figure 1. iAPX 86/10 CPU Block Diagram



40 LEAD

Figure 2. iAPX 86/10 Pin Configuration

Table 1. Pin Description

The following pin function descriptions are for iAPX 86 systems in either minimum or maximum mode. The "Local Bus" in these descriptions is the direct multiplexed bus interface connection to the 8086 (without regard to additional bus buffers).

Symbol	Pin No.	Type	Name and Function
AD_{15}-AD_0	2-16, 39	I/O	**Address Data Bus:** These lines constitute the time multiplexed memory/IO address (T_1) and data (T_2, T_3, T_W, T_4) bus. A_0 is analogous to $\overline{BHE}$ for the lower byte of the data bus, pins D_7-D_0. It is LOW during T_1 when a byte is to be transferred on the lower portion of the bus in memory or I/O operations. Eight-bit oriented devices tied to the lower half would normally use A_0 to condition chip select functions. (See $\overline{BHE}$.) These lines are active HIGH and float to 3-state OFF during interrupt acknowledge and local bus "hold acknowledge."
A_{19}/S_6, A_{18}/S_5, A_{17}/S_4, A_{16}/S_3	35-38	O	**Address/Status:** During T_1 these are the four most significant address lines for memory operations. During I/O operations these lines are LOW. During memory and I/O operations, status information is available on these lines during T_2, T_3, T_W, and T_4. The status of the interrupt enable FLAG bit (S_5) is updated at the beginning of each CLK cycle. A_{17}/S_4 and A_{16}/S_3 are encoded as shown. This information indicates which relocation register is presently being used for data accessing. These lines float to 3-state OFF during local bus "hold acknowledge." A_{17}/S_4 / A_{16}/S_3 / Characteristics 0 (LOW) / 0 / Alternate Data 0 / 1 / Stack 1 (HIGH) / 0 / Code or None 1 / 1 / Data S_6 is 0 (LOW)
$\overline{BHE}/S_7$	34	O	**Bus High Enable/Status:** During T_1 the bus high enable signal ($\overline{BHE}$) should be used to enable data onto the most significant half of the data bus, pins D_{15}-D_8. Eight-bit oriented devices tied to the upper half of the bus would normally use $\overline{BHE}$ to condition chip select functions. $\overline{BHE}$ is LOW during T_1 for read, write, and interrupt acknowledge cycles when a byte is to be transferred on the high portion of the bus. The S_7 status information is available during T_2, T_3, and T_4. The signal is active LOW, and floats to 3-state OFF in "hold." It is LOW during T_1 for the first interrupt acknowledge cycle. $\overline{BHE}$ / A_0 / Characteristics 0 / 0 / Whole word 0 / 1 / Upper byte from/ to odd address 1 / 0 / Lower byte from/ to even address 1 / 1 / None
$\overline{RD}$	32	O	**Read:** Read strobe indicates that the processor is performing a memory of I/O read cycle, depending on the state of the S_2 pin. This signal is used to read devices which reside on the 8086 local bus. $\overline{RD}$ is active LOW during T_2, T_3 and T_W of any read cycle, and is guaranteed to remain HIGH in T_2 until the 8086 local bus has floated. This signal floats to 3-state OFF in "hold acknowledge."
READY	22	I	**READY:** is the acknowledgement from the addressed memory or I/O device that it will complete the data transfer. The READY signal from memory/IO is synchronized by the 8284A Clock Generator to form READY. This signal is active HIGH. The 8086 READY input is not synchronized. Correct operation is not guaranteed if the setup and hold times are not met.
INTR	18	I	**Interrupt Request:** is a level triggered input which is sampled during the last clock cycle of each instruction to determine if the processor should enter into an interrupt acknowledge operation. A subroutine is vectored to via an interrupt vector lookup table located in system memory. It can be internally masked by software resetting the interrupt enable bit. INTR is internally synchronized. This signal is active HIGH.
$\overline{TEST}$	23	I	**$\overline{TEST}$:** Input is examined by the "Wait" instruction. If the $\overline{TEST}$ input is LOW execution continues, otherwise the processor waits in an "Idle" state. This input is synchronized internally during each clock cycle on the leading edge of CLK.

Table 1. Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
NMI	17	I	**Non-maskable interrupt:** an edge triggered input which causes a type 2 interrupt. A subroutine is vectored to via an interrupt vector lookup table located in system memory. NMI is not maskable internally by software. A transition from a LOW to HIGH initiates the interrupt at the end of the current instruction. This input is internally synchronized.
RESET	21	I	**Reset:** causes the processor to immediately terminate its present activity. The signal must be active HIGH for at least four clock cycles. It restarts execution, as described in the Instruction Set description, when RESET returns LOW. RESET is internally synchronized.
CLK	19	I	**Clock:** provides the basic timing for the processor and bus controller. It is asymmetric with a 33% duty cycle to provide optimized internal timing.
V_{CC}	40		V_{CC}: +5V power supply pin.
GND	1, 20		**Ground**
MN/$\overline{MX}$	33	I	**Minimum/Maximum:** indicates what mode the processor is to operate in. The two modes are discussed in the following sections.

The following pin function descriptions are for the 8086/8288 system in maximum mode (i.e., MN/$\overline{MX}$ = V_{SS}). Only the pin functions which are unique to maximum mode are described; all other pin functions are as described above.

$\overline{S_2}$, $\overline{S_1}$, $\overline{S_0}$	26-28	O	**Status:** active during T_4, T_1, and T_2 and is returned to the passive state (1,1,1) during T_3 or during T_W when READY is HIGH. This status is used by the 8288 Bus Controller to generate all memory and I/O access control signals. Any change by $\overline{S_2}$, $\overline{S_1}$, or $\overline{S_0}$ during T_4 is used to indicate the beginning of a bus cycle, and the return to the passive state in T_3 or T_W is used to indicate the end of a bus cycle. These signals float to 3-state OFF in "hold acknowledge." These status lines are encoded as shown.

$\overline{S_2}$	$\overline{S_1}$	$\overline{S_0}$	Characteristics
0 (LOW)	0	0	Interrupt Acknowledge
0	0	1	Read I/O Port
0	1	0	Write I/O Port
0	1	1	Halt
1 (HIGH)	0	0	Code Access
1	0	1	Read Memory
1	1	0	Write Memory
1	1	1	Passive

$\overline{RQ}/\overline{GT_0}$, $\overline{RQ}/\overline{GT_1}$	30, 31	I/O	**Request/Grant:** pins are used by other local bus masters to force the processor to release the local bus at the end of the processor's current bus cycle. Each pin is bidirectional with $\overline{RQ}/\overline{GT_0}$ having higher priority than $\overline{RQ}/\overline{GT_1}$. $\overline{RQ}/\overline{GT}$ has an internal pull-up resistor so may be left unconnected. The request/grant sequence is as follows (see Figure 9): 1. A pulse of 1 CLK wide from another local bus master indicates a local bus request ("hold") to the 8086 (pulse 1). 2. During a T_4 or T_1 clock cycle, a pulse 1 CLK wide from the 8086 to the requesting master (pulse 2), indicates that the 8086 has allowed the local bus to float and that it will enter the "hold acknowledge" state at the next CLK. The CPU's bus interface unit is disconnected logically from the local bus during "hold acknowledge." 3. A pulse 1 CLK wide from the requesting master indicates to the 8086 (pulse 3) that the "hold" request is about to end and that the 8086 can reclaim the local bus at the next CLK. Each master-master exchange of the local bus is a sequence of 3 pulses. There must be one dead CLK cycle after each bus exchange. Pulses are active LOW. If the request is made while the CPU is performing a memory cycle, it will release the local bus during T_4 of the cycle when all the following conditions are met: 1. Request occurs on or before T_2. 2. Current cycle is not the low byte of a word (on an odd address). 3. Current cycle is not the first acknowledge of an interrupt acknowledge sequence. 4. A locked instruction is not currently executing.

Table 1. Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
			If the local bus is idle when the request is made the two possible events will follow: 1. Local bus will be released during the next clock. 2. A memory cycle will start within 3 clocks. Now the four rules for a currently active memory cycle apply with condition number 1 already satisfied.
$\overline{LOCK}$	29	O	**$\overline{LOCK}$:** output indicates that other system bus masters are not to gain control of the system bus while $\overline{LOCK}$ is active LOW. The $\overline{LOCK}$ signal is activated by the "LOCK" prefix instruction and remains active until the completion of the next instruction. This signal is active LOW, and floats to 3-state OFF in "hold acknowledge."
QS_1, QS_0	24, 25	O	**Queue Status:** The queue status is valid during the CLK cycle after which the queue operation is performed. QS_1 and QS_0 provide status to allow external tracking of the internal 8086 instruction queue. QS_1 / QS_0 / CHARACTERISTICS 0 (LOW) / 0 / No Operation 0 / 1 / First Byte of Op Code from Queue 1 (HIGH) / 0 / Empty the Queue 1 / 1 / Subsequent Byte from Queue

The following pin function descriptions are for the 8086 in minimum mode (i.e., MN/$\overline{MX}$ = V_{CC}). Only the pin functions which are unique to minimum mode are described; all other pin functions are as described above.

M/$\overline{IO}$	28	O	**Status line:** logically equivalent to S_2 in the maximum mode. It is used to distinguish a memory access from an I/O access. M/$\overline{IO}$ becomes valid in the T_4 preceding a bus cycle and remains valid until the final T_4 of the cycle (M = HIGH, IO = LOW). M/$\overline{IO}$ floats to 3-state OFF in local bus "hold acknowledge."
$\overline{WR}$	29	O	**Write:** indicates that the processor is performing a write memory or write I/O cycle, depending on the state of the M/$\overline{IO}$ signal. $\overline{WR}$ is active for T_2, T_3 and T_W of any write cycle. It is active LOW, and floats to 3-state OFF in local bus "hold acknowledge."
$\overline{INTA}$	24	O	**$\overline{INTA}$** is used as a read strobe for interrupt acknowledge cycles. It is active LOW during T_2, T_3 and T_W of each interrupt acknowledge cycle.
ALE	25	O	**Address Latch Enable:** provided by the processor to latch the address into the 8282/8283 address latch. It is a HIGH pulse active during T_1 of any bus cycle. Note that ALE is never floated.
DT/$\overline{R}$	27	O	**Data Transmit/Receive:** needed in minimum system that desires to use an 8286/8287 data bus transceiver. It is used to control the direction of data flow through the transceiver. Logically DT/$\overline{R}$ is equivalent to $\overline{S_1}$ in the maximum mode, and its timing is the same as for M/$\overline{IO}$. (T = HIGH, R = LOW.) This signal floats to 3-state OFF in local bus "hold acknowledge."
$\overline{DEN}$	26	O	**Data Enable:** provided as an output enable for the 8286/8287 in a minimum system which uses the transceiver. $\overline{DEN}$ is active LOW during each memory and I/O access and for INTA cycles. For a read or $\overline{INTA}$ cycle it is active from the middle of T_2 until the middle of T_4, while for a write cycle it is active from the beginning of T_2 until the middle of T_4. $\overline{DEN}$ floats to 3-state OFF in local bus "hold acknowledge."
HOLD, HLDA	31, 30	I/O	**HOLD:** indicates that another master is requesting a local bus "hold." To be acknowledged, HOLD must be active HIGH. The processor receiving the "hold" request will issue HLDA (HIGH) as an acknowledgement in the middle of a T_1 clock cycle. Simultaneous with the issuance of HLDA the processor will float the local bus and control lines. After HOLD is detected as being LOW, the processor will LOWer the HLDA, and when the processor needs to run another cycle, it will again drive the local bus and control lines. The same rules as for $\overline{RQ}/\overline{GT}$ apply regarding when the local bus will be released. HOLD is not an asynchronous input. External synchronization should be provided if the system cannot otherwise guarantee the setup time.

FUNCTIONAL DESCRIPTION

GENERAL OPERATION

The internal functions of the iAPX 86/10 processor are partitioned logically into two processing units. The first is the Bus Interface Unit (BIU) and the second is the Execution Unit (EU) as shown in the block diagram of Figure 1.

These units can interact directly but for the most part perform as separate asynchronous operational processors. The bus interface unit provides the functions related to instruction fetching and queuing, operand fetch and store, and address relocation. This unit also provides the basic bus control. The overlap of instruction pre-fetching provided by this unit serves to increase processor performance through improved bus bandwidth utilization. Up to 6 bytes of the instruction stream can be queued while waiting for decoding and execution.

The instruction stream queuing mechanism allows the BIU to keep the memory utilized very efficiently. Whenever there is space for at least 2 bytes in the queue, the BIU will attempt a word fetch memory cycle. This greatly reduces "dead time" on the memory bus. The queue acts as a First-In-First-Out (FIFO) buffer, from which the EU extracts instruction bytes as required. If the queue is empty (following a branch instruction, for example), the first byte into the queue immediately becomes available to the EU.

The execution unit receives pre-fetched instructions from the BIU queue and provides un-relocated operand addresses to the BIU. Memory operands are passed through the BIU for processing by the EU, which passes results to the BIU for storage. See the Instruction Set description for further register set and architectural descriptions.

MEMORY ORGANIZATION

The processor provides a 20-bit address to memory which locates the byte being referenced. The memory is organized as a linear array of up to 1 million bytes, addressed as 00000(H) to FFFFF(H). The memory is logically divided into code, data, extra data, and stack segments of up to 64K bytes each, with each segment falling on 16-byte boundaries. (See Figure 3a.)

All memory references are made relative to base addresses contained in high speed segment registers. The segment types were chosen based on the addressing needs of programs. The segment register to be selected is automatically chosen according to the rules of the following table. All information in one segment type share the same logical attributes (e.g. code or data). By structuring memory into relocatable areas of similar characteristics and by automatically selecting segment registers, programs are shorter, faster, and more structured.

Word (16-bit) operands can be located on even or odd address boundaries and are thus not constrained to even boundaries as is the case in many 16-bit computers. For address and data operands, the least significant byte of the word is stored in the lower valued address location and the most significant byte in the next higher address location. The BIU automatically performs the proper number of memory accesses, one if the word operand is on an even byte boundary and two if it is on an odd byte boundary. Except for the performance penalty, this double access is transparent to the software. This performance penalty does not occur for instruction fetches, only word operands.

Physically, the memory is organized as a high bank (D_{15}–D_8) and a low bank (D_7–D_0) of 512K 8-bit bytes addressed in parallel by the processor's address lines

A_{19} - A_1. Byte data with even addresses is transferred on the D_7-D_0 bus lines while odd addressed byte data (A_0 HIGH) is transferred on the D_{15}-D_8 bus lines. The processor provides two enable signals, $\overline{BHE}$ and A_0, to selectively allow reading from or writing into either an odd byte location, even byte location, or both. The instruction stream is fetched from memory as words and is addressed internally by the processor to the byte level as necessary.

Memory Reference Need	Segment Register Used	Segment Selection Rule
Instructions	CODE (CS)	Automatic with all instruction prefetch.
Stack	STACK (SS)	All stack pushes and pops. Memory references relative to BP base register except data references.
Local Data	DATA (DS)	Data references when: relative to stack, destination of string operation, or explicitly overridden.
External (Global) Data	EXTRA (ES)	Destination of string operations: Explicitly selected using a segment override.

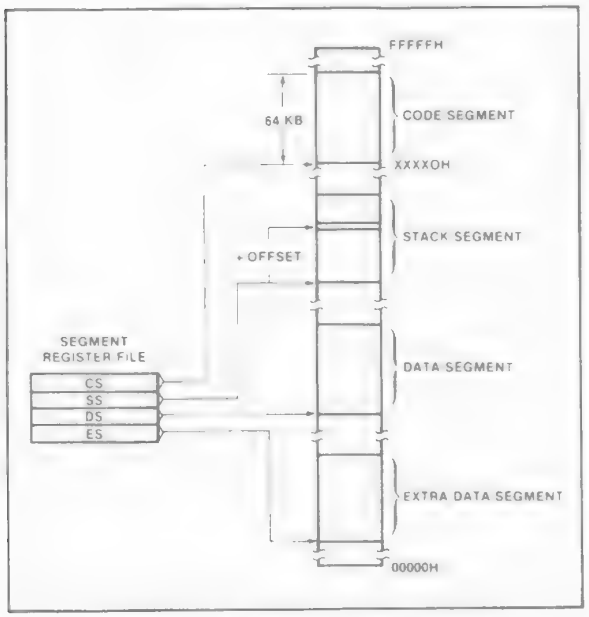


Figure 3a. Memory Organization

In referencing word data the BIU requires one or two memory cycles depending on whether or not the starting byte of the word is on an even or odd address, respectively. Consequently, in referencing word operands performance can be optimized by locating data on even address boundaries. This is an especially useful technique for using the stack, since odd address references to the stack may adversely affect the context switching time for interrupt processing or task multiplexing.

Certain locations in memory are reserved for specific CPU operations (see Figure 3b.) Locations from address FFFF0H through FFFFFH are reserved for operations including a jump to the initial program loading routine. Following RESET, the CPU will always begin execution at location FFFF0H where the jump must be. Locations 00000H through 003FFH are reserved for interrupt operations. Each of the 256 possible interrupt types has its service routine pointed to by a 4-byte pointer element consisting of a 16-bit segment address and a 16-bit offset address. The pointer elements are assumed to have been stored at the respective places in reserved memory prior to occurrence of interrupts.

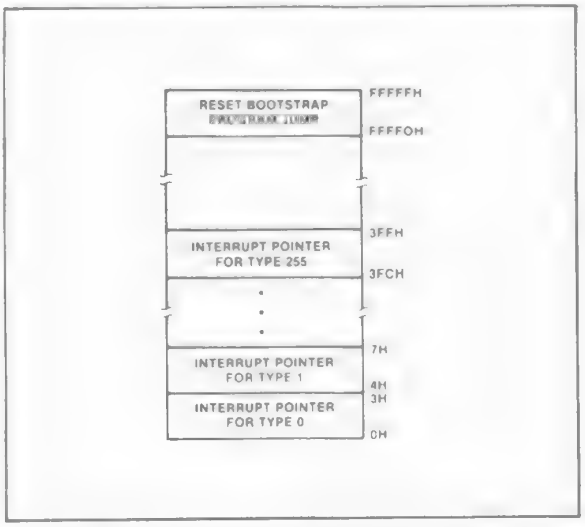


Figure 3b. Reserved Memory Locations

MINIMUM AND MAXIMUM MODES

The requirements for supporting minimum and maximum iAPX 86/10 systems are sufficiently different that they cannot be done efficiently with 40 uniquely defined pins. Consequently, the 8086 is equipped with a strap pin (MN/$\overline{MX}$) which defines the system configuration. The definition of a certain subset of the pins changes dependent on the condition of the strap pin. When MN/$\overline{MX}$ pin is strapped to GND, the 8086 treats pins 24 through 31 in maximum mode. An 8288 bus controller interprets status information coded into $\overline{S}_0$,$\overline{S}_1$,$\overline{S}_2$ to generate bus timing and control signals compatible with the MULTIBUS™ architecture. When the MN/$\overline{MX}$ pin is strapped to V_{CC}, the 8086 generates bus control signals itself on pins 24 through 31, as shown in parentheses in Figure 2. Examples of minimum mode and maximum mode systems are shown in Figure 4.

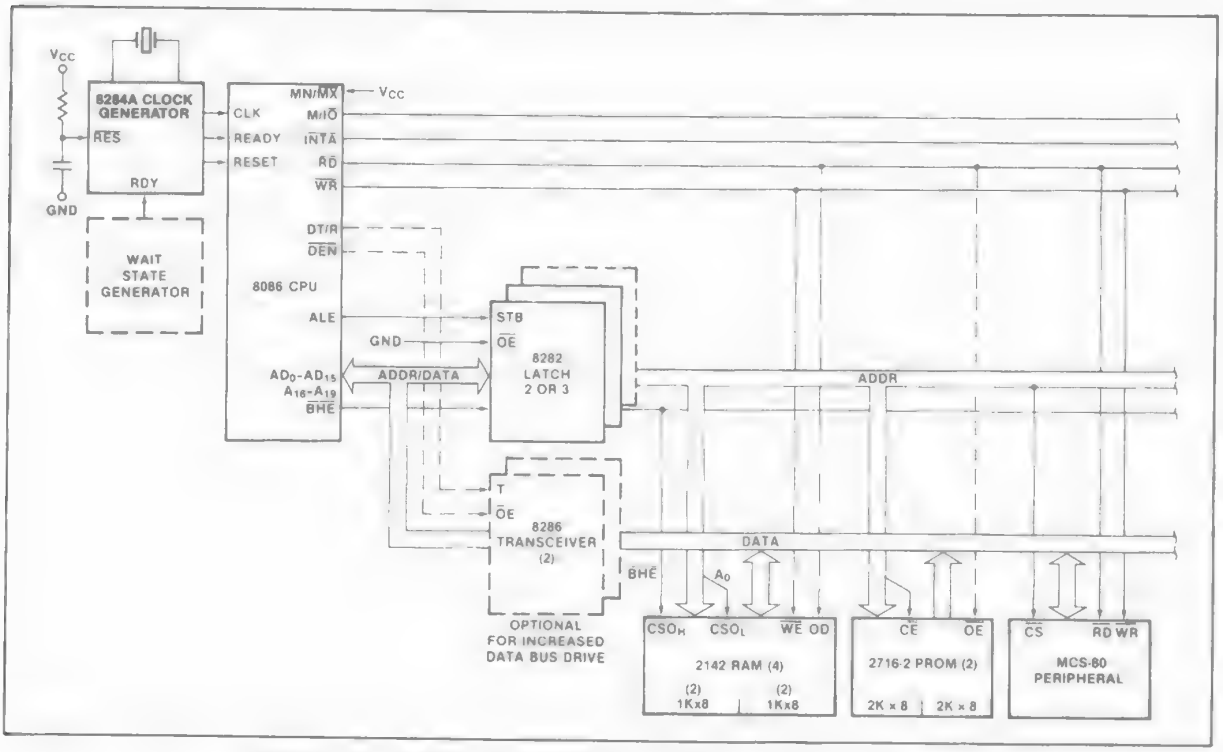


Figure 4a. Minimum Mode iAPX 86/10 Typical Configuration

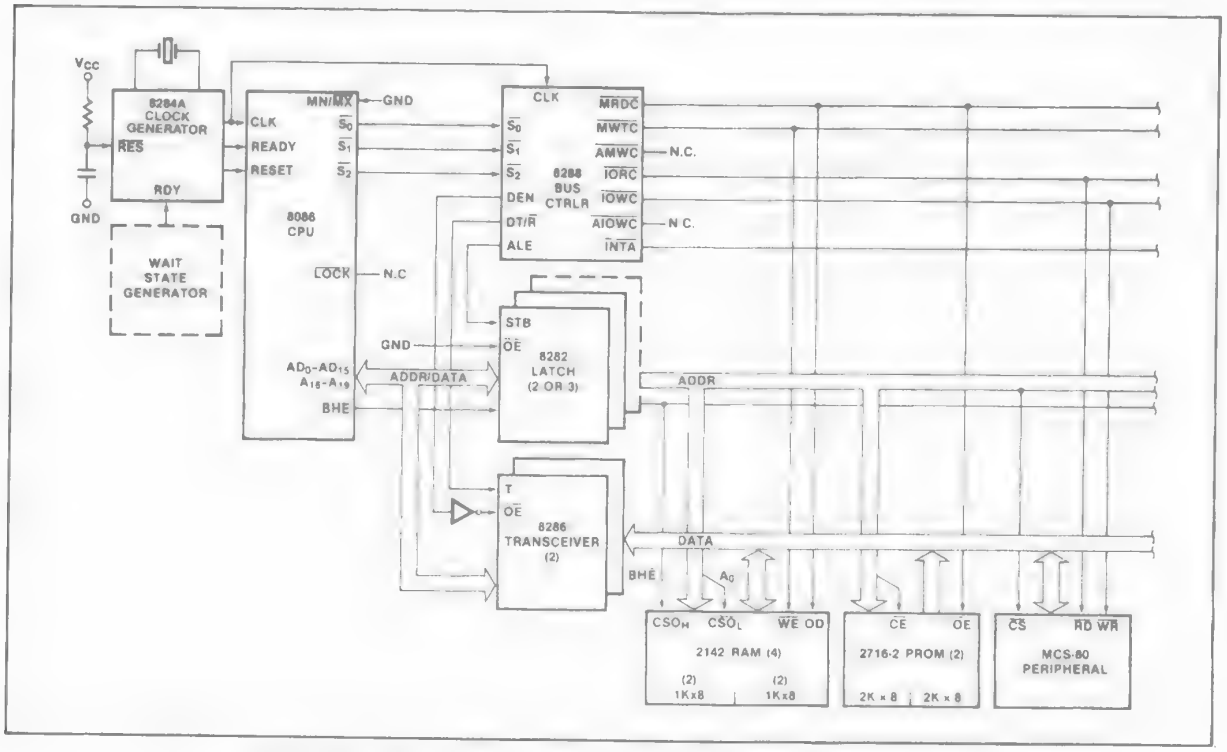


Figure 4b. Maximum Mode iAPX 86/10 Typical Configuration

BUS OPERATION

The 86/10 has a combined address and data bus commonly referred to as a time multiplexed bus. This technique provides the most efficient use of pins on the processor while permitting the use of a standard 40-lead package. This "local bus" can be buffered directly and used throughout the system with address latching provided on memory and I/O modules. In addition, the bus can also be demultiplexed at the processor with a single set of address latches if a standard non-multiplexed bus is desired for the system.

Each processor bus cycle consists of at least four CLK cycles. These are referred to as T_1, T_2, T_3 and T_4 (see Figure 5). The address is emitted from the processor during T_1 and data transfer occurs on the bus during T_3 and T_4. T_2 is used primarily for changing the direction of the bus during read operations. In the event that a "NOT READY" indication is given by the addressed device, "Wait" states (T_W) are inserted between T_3 and T_4. Each inserted "Wait" state is of the same duration as a CLK cycle. Periods can occur between 8086 bus cycles. These are referred to as "Idle" states (T_I) or inactive CLK cycles. The processor uses these cycles for internal housekeeping.

During T_1 of any bus cycle the ALE (Address Latch Enable) signal is emitted (by either the processor or the 8288 bus controller, depending on the MN/$\overline{MX}$ strap). At the trailing edge of this pulse, a valid address and certain status information for the cycle may be latched.

Status bits $\overline{S_0}$, $\overline{S_1}$, and $\overline{S_2}$ are used, in maximum mode, by the bus controller to identify the type of bus transaction according to the following table:

$\overline{S_2}$	$\overline{S_1}$	$\overline{S_0}$	CHARACTERISTICS
0 (LOW)	0	0	Interrupt Acknowledge
0	0	1	Read I/O
0	1	0	Write I/O
0	1	1	Halt
1 (HIGH)	0	0	Instruction Fetch
1	0	1	Read Data from Memory
1	1	0	Write Data to Memory
1	1	1	Passive (no bus cycle)

Status bits S_3 through S_7 are multiplexed with high-order address bits and the $\overline{BHE}$ signal, and are therefore valid during T_2 through T_4. S_3 and S_4 indicate which segment register (see Instruction Set description) was used for this bus cycle in forming the address, according to the following table:

S_4	S_3	CHARACTERISTICS
0 (LOW)	0	Alternate Data (extra segment)
0	1	Stack
1 (HIGH)	0	Code or None
1	1	Data

S_5 is a reflection of the PSW interrupt enable bit. S_6=0 and S_7 is a spare status bit.

I/O ADDRESSING

In the 86/10, I/O operations can address up to a maximum of 64K I/O byte registers or 32K I/O word registers. The I/O address appears in the same format as the memory address on bus lines A_{15}-A_0. The address lines A_{19}-A_{16} are zero in I/O operations. The variable I/O instructions which use register DX as a pointer have full address capability while the direct I/O instructions directly address one or two of the 256 I/O byte locations in page 0 of the I/O address space.

I/O ports are addressed in the same manner as memory locations. Even addressed bytes are transferred on the D_7-D_0 bus lines and odd addressed bytes on D_{15}-D_8. Care must be taken to assure that each register within an 8-bit peripheral located on the lower portion of the bus be addressed as even.

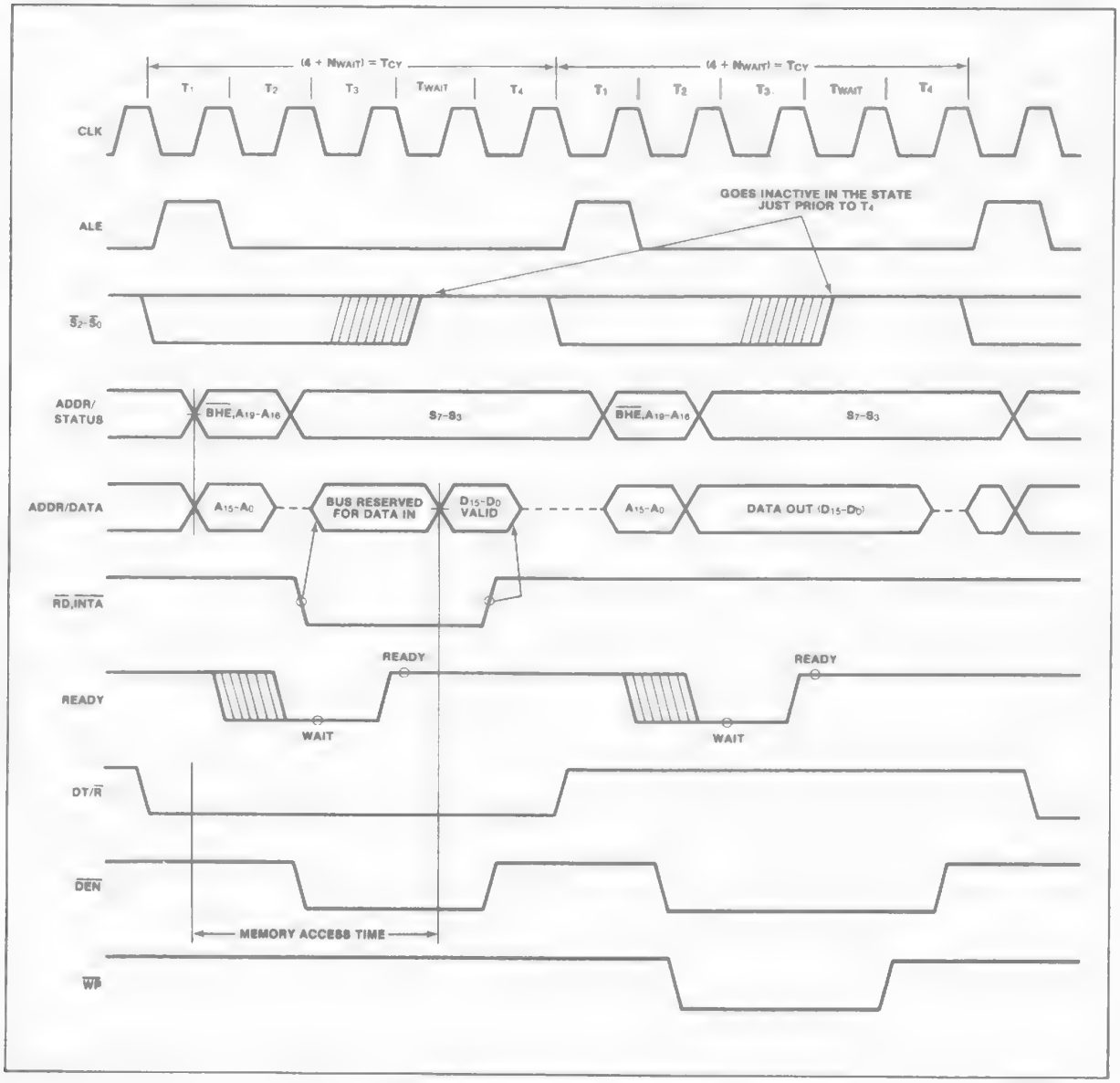


Figure 5. Basic System Timing

EXTERNAL INTERFACE

PROCESSOR RESET AND INITIALIZATION

Processor initialization or start up is accomplished with activation (HIGH) of the RESET pin. The 8086 RESET is required to be HIGH for greater than 4 CLK cycles. The 8086 will terminate operations on the high-going edge of RESET and will remain dormant as long as RESET is HIGH. The low-going transition of RESET triggers an internal reset sequence for approximately 10 CLK cycles. After this interval the 8086 operates normally beginning with the instruction in absolute location FFFF0H (see Figure 3B). The details of this operation are specified in the Instruction Set description of the MCS-86 Family User's Manual. The RESET input is internally synchronized to the processor clock. At initialization the HIGH-to-LOW transition of RESET must occur no sooner than 50 μs after power-up, to allow complete initialization of the 8086.

NMI may not be asserted prior to the 2nd CLK cycle following the end of RESET.

INTERRUPT OPERATIONS

Interrupt operations fall into two classes; software or hardware initiated. The software initiated interrupts and software aspects of hardware interrupts are specified in the Instruction Set description. Hardware interrupts can be classified as non-maskable or maskable.

Interrupts result in a transfer of control to a new program location. A 256-element table containing address pointers to the interrupt service program locations resides in absolute locations 0 through 3FFH (see Figure 3b), which are reserved for this purpose. Each element in the table is 4 bytes in size and corresponds to an interrupt "type". An interrupting device supplies an 8-bit type number, during the interrupt acknowledge sequence, which is used to "vector" through the appropriate element to the new interrupt service program location.

NON-MASKABLE INTERRUPT (NMI)

The processor provides a single non-maskable interrupt pin (NMI) which has higher priority than the maskable interrupt request pin (INTR). A typical use would be to activate a power failure routine. The NMI is edge-triggered on a LOW-to-HIGH transition. The activation of this pin causes a type 2 interrupt. (See Instruction Set description.)

NMI is required to have a duration in the HIGH state of greater than two CLK cycles, but is not required to be synchronized to the clock. Any high-going transition of NMI is latched on-chip and will be serviced at the end of the current instruction or between whole moves of a block-type instruction. Worst case response to NMI would be for multiply, divide, and variable shift instructions. There is no specification on the occurrence of the low-going edge; it may occur before, during, or after the servicing of NMI. Another high-going edge triggers another response if it occurs after the start of the NMI procedure. The signal must be free of logical spikes in general and be free of bounces on the low-going edge to avoid triggering extraneous responses.

MASKABLE INTERRUPT (INTR)

The 86/10 provides a single interrupt request input (INTR) which can be masked internally by software with the resetting of the interrupt enable FLAG status bit. The interrupt request signal is level triggered. It is internally synchronized during each clock cycle on the high-going edge of CLK. To be responded to, INTR must be present (HIGH) during the clock period preceding the end of the current instruction or the end of a whole move for a block-type instruction. During the interrupt response sequence further interrupts are disabled. The enable bit is reset as part of the response to any interrupt (INTR, NMI, software interrupt or single-step), although the

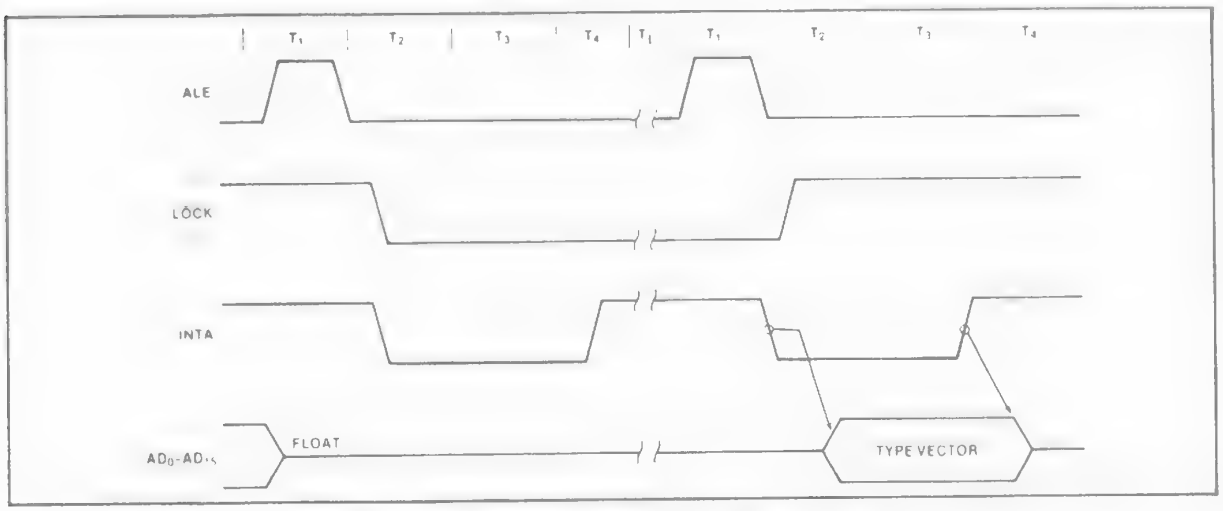


Figure 6. Interrupt Acknowledge Sequence

AFN-01497D

FLAGS register which is automatically pushed onto the stack reflects the state of the processor prior to the interrupt. Until the old FLAGS register is restored the enable bit will be zero unless specifically set by an instruction.

During the response sequence (figure 6) the processor executes two successive (back-to-back) interrupt acknowledge cycles. The 8086 emits the LOCK signal from T_2 of the first bus cycle until T_2 of the second. A local bus "hold" request will not be honored until the end of the second bus cycle. In the second bus cycle a byte is fetched from the external interrupt system (e.g., 8259A PIC) which identifies the source (type) of the interrupt. This byte is multiplied by four and used as a pointer into the interrupt vector lookup table. An INTR signal left HIGH will be continually responded to within the limitations of the enable bit and sample period. The INTERRUPT RETURN instruction includes a FLAGS pop which returns the status of the original interrupt enable bit when it restores the FLAGS.

HALT

When a software "HALT" instruction is executed the processor indicates that it is entering the "HALT" state in one of two ways depending upon which mode is strapped. In minimum mode, the processor issues one ALE with no qualifying bus control signals. In Maximum Mode, the processor issues appropriate HALT status on $\overline{S}_2\overline{S}_1\overline{S}_0$ and the 8288 bus controller issues one ALE. The 8086 will not leave the "HALT" state when a local bus "hold" is entered while in "HALT". In this case, the processor reissues the HALT indicator. An interrupt request or RESET will force the 8086 out of the "HALT" state.

READ/MODIFY/WRITE (SEMAPHORE) OPERATIONS VIA LOCK

The $\overline{LOCK}$ status information is provided by the processor when directly consecutive bus cycles are required during the execution of an instruction. This provides the processor with the capability of performing read/modify/write operations on memory (via the Exchange Register With Memory instruction, for example) without the possibility of another system bus master receiving intervening memory cycles. This is useful in multiprocessor system configurations to accomplish "test and set lock" operations. The $\overline{LOCK}$ signal is activated (forced LOW) in the clock cycle following the one in which the software "LOCK" prefix instruction is decoded by the EU. It is deactivated at the end of the last bus cycle of the instruction following the "LOCK" prefix instruction. While $\overline{LOCK}$ is active a request on a RQ/GT pin will be recorded and then honored at the end of the LOCK.

EXTERNAL SYNCHRONIZATION VIA TEST

As an alternative to the interrupts and general I/O capabilities, the 8086 provides a single software-testable input known as the $\overline{TEST}$ signal. At any time the program may execute a WAIT instruction. If at that time the $\overline{TEST}$ signal is inactive (HIGH), program execution becomes suspended while the processor waits for $\overline{TEST}$ to become active. It must remain active for at least 5 CLK cycles. The WAIT instruction is re-executed repeatedly until that time. This activity does not consume bus cycles. The processor remains in an idle state while waiting. All 8086 drivers go to 3-state OFF if bus "Hold" is entered. If interrupts are enabled, they may occur while the processor is waiting. When this occurs the processor fetches the WAIT instruction one extra time, processes the interrupt, and then re-fetches and re-executes the WAIT instruction upon returning from the interrupt.

BASIC SYSTEM TIMING

Typical system configurations for the processor operating in minimum mode and in maximum mode are shown in Figures 4a and 4b, respectively. In minimum mode, the MN/$\overline{MX}$ pin is strapped to V_{CC} and the processor emits bus control signals in a manner similar to the 8085. In maximum mode, the MN/$\overline{MX}$ pin is strapped to V_{SS} and the processor emits coded status information which the 8288 bus controller uses to generate MULTIBUS compatible bus control signals. Figure 5 illustrates the signal timing relationships.

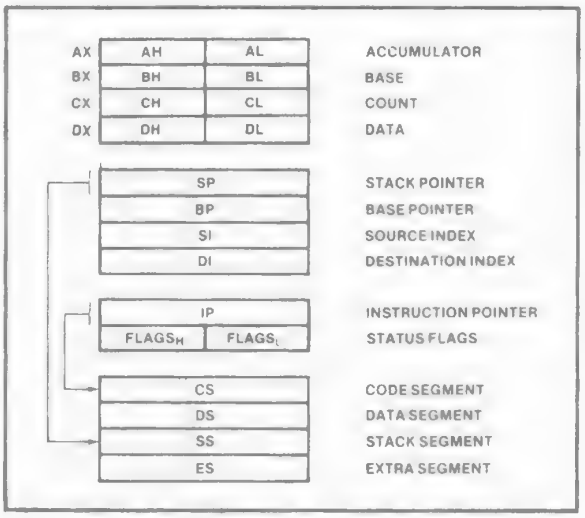


Figure 7. iAPX 86/10 Register Model

SYSTEM TIMING — MINIMUM SYSTEM

The read cycle begins in T_1 with the assertion of the Address Latch Enable (ALE) signal. The trailing (low-going) edge of this signal is used to latch the address information, which is valid on the local bus at this time, into the 8282/8283 latch. The $\overline{BHE}$ and A_0 signals address the low, high, or both bytes. From T_1 to T_4 the M/$\overline{IO}$ signal indicates a memory or I/O operation. At T_2 the address is removed from the local bus and the bus goes to a high impedance state. The read control signal is also asserted at T_2. The read ($\overline{RD}$) signal causes the addressed device to enable its data bus drivers to the local bus. Some time later valid data will be available on the bus and the addressed device will drive the READY line HIGH. When the processor returns the read signal

to a HIGH level, the addressed device will again 3-state its bus drivers. If a transceiver (8286/8287) is required to buffer the 8086 local bus, signals DT/$\overline{R}$ and $\overline{DEN}$ are provided by the 8086.

A write cycle also begins with the assertion of ALE and the emission of the address. The M/$\overline{IO}$ signal is again asserted to indicate a memory or I/O write operation. In the T_2 immediately following the address emission the processor emits the data to be written into the addressed location. This data remains valid until the middle of T_4. During T_2, T_3, and T_W the processor asserts the write control signal. The write ($\overline{WR}$) signal becomes active at the beginning of T_2 as opposed to the read which is delayed somewhat into T_2 to provide time for the bus to float.

The $\overline{BHE}$ and A_0 signals are used to select the proper byte(s) of the memory/IO word to be read or written according to the following table:

$\overline{BHE}$	A0	CHARACTERISTICS
0	0	Whole word
0	1	Upper byte from/ to odd address
1	0	Lower byte from/ to even address
1	1	None

I/O ports are addressed in the same manner as memory location. Even addressed bytes are transferred on the D_7–D_0 bus lines and odd addressed bytes on D_{15}–D_8.

The basic difference between the interrupt acknowledge cycle and a read cycle is that the interrupt acknowledge signal ($\overline{INTA}$) is asserted in place of the read ($\overline{RD}$) signal and the address bus is floated. (See Figure 6.) In the second of two successive INTA cycles, a byte of information is read from bus lines D_7–D_0 as supplied by the interrupt system logic (i.e., 8259A Priority Interrupt Controller). This byte identifies the source (type) of the interrupt. It is multiplied by four and used as a pointer into an interrupt vector lookup table, as described earlier.

BUS TIMING—MEDIUM SIZE SYSTEMS

For medium size systems the MN/$\overline{MX}$ pin is connected to V_{SS} and the 8288 Bus Controller is added to the system as well as an 8282/8283 latch for latching the system address, and a 8286/8287 transceiver to allow for bus loading greater than the 8086 is capable of handling. Signals ALE, DEN, and DT/$\overline{R}$ are generated by the 8288 instead of the processor in this configuration although their timing remains relatively the same. The 8086 status outputs ($\overline{S}_2$, $\overline{S}_1$, and $\overline{S}_0$) provide type-of-cycle information and become 8288 inputs. This bus cycle information specifies read (code, data, or I/O), write (data or I/O), interrupt acknowledge, or software halt. The 8288 thus issues control signals specifying memory read or write, I/O read or write, or interrupt acknowledge. The 8288 provides two types of write strobes, normal and advanced, to be applied as required. The normal write strobes have data valid at the leading edge of write. The advanced write strobes have the same timing as read strobes, and hence data isn't valid at the leading edge of write. The 8286/8287 transceiver receives the usual T and OE inputs from the 8288's DT/$\overline{R}$ and DEN.

The pointer into the interrupt vector table, which is passed during the second INTA cycle, can derive from an 8259A located on either the local bus or the system bus. If the master 8259A Priority Interrupt Controller is positioned on the local bus, a TTL gate is required to disable the 8286/8287 transceiver when reading from the master 8259A during the interrupt acknowledge sequence and software "poll".

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias . . . . . 0°C to 70°C
Storage Temperature . . . . . – 65°C to + 150°C
Voltage on Any Pin with
Respect to Ground . . . . . – 1.0 to + 7V
Power Dissipation . . . . . 2.5 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS

(8086: T_A = 0°C to 70°C, V_{CC} = 5V ± 10%)
(8086-1: T_A = 0°C to 70°C, V_{CC} = 5V ± 5%)
(8086-2: T_A = 0°C to 70°C, V_{CC} = 5V ± 5%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	– 0.5	+ 0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2.5 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = – 400 μA
I_{CC}	Power Supply Current: 8086 8086-1 8086-2		340 360 350	mA	T_A = 25°C
I_{LI}	Input Leakage Current		± 10	μA	0V ≤ V_{IN} ≤ V_{CC}
I_{LO}	Output Leakage Current		± 10	μA	0.45V ≤ V_{OUT} ≤ V_{CC}
V_{CL}	Clock Input Low Voltage	– 0.5	+ 0.6	V	
V_{CH}	Clock Input High Voltage	3.9	V_{CC} + 1.0	V	
C_{IN}	Capacitance of Input Buffer (All input except $AD_0 - AD_{15}$, $\overline{RQ}/\overline{GT}$)		15	pF	fc = 1 MHz
C_{IO}	Capacitance of I/O Buffer ($AD_0 - AD_{15}$, $\overline{RQ}/\overline{GT}$)		15	pF	fc = 1 MHz

A.C. CHARACTERISTICS (8086: T_A = 0°C to 70°C, V_{CC} = 5V ± 10%)
(8086-1: T_A = 0°C to 70°C, V_{CC} = 5V ± 5%)
(8086-2: T_A = 0°C to 70°C, V_{CC} = 5V ± 5%)

MINIMUM COMPLEXITY SYSTEM TIMING REQUIREMENTS

Symbol	Parameter	8086		8086-1 (Preliminary)		8086-2		Units	Test Conditions
		Min.	Max.	Min.	Max.	Min.	Max.		
TCLCL	CLK Cycle Period	100	500	100	500	125	500	ns	
TCLCH	CLK Low Time	118		53		[illegible]		[illegible]	
TCHCL	CLK High Time	69		39		44		[illegible]	
TCH1CH2	CLK Rise Time		10		10		10	ns	From 1.0V to 3.5V
TCL2CL1	CLK Fall Time		10		10		10	ns	From 3.5V to 1.0V
TDVCL	Data in Setup Time	[illegible]		[illegible]		[illegible]		ns	
TCLDX	Data in Hold Time	10		10		10		ns	
TR1VCL	RDY Setup Time into 8284A (See Notes 1, 2)	35		35		35		ns	
TCLR1X	RDY Hold Time into 8284A (See Notes 1, 2)	0		0		0		ns	
TRYHCH	READY Setup Time into 8086	118		53		68		ns	
TCHRYX	READY Hold Time into 8086	30		20		20		ns	
TRYLCL	READY Inactive to CLK (See Note 3)	−8		−10		−8		ns	
THVCH	HOLD Setup Time	35		[illegible]		[illegible]		ns	
TINVCH	INTR, NMI, $\overline{TEST}$ Setup Time (See Note 2)	30		15		15		ns	
TILIH	Input Rise Time (Except CLK)		[illegible]		[illegible]		20	ns	From 0.8V to 2.0V
TIHIL	Input Fall Time (Except CLK)		12		12		12	ns	From 2.0V to 0.8V

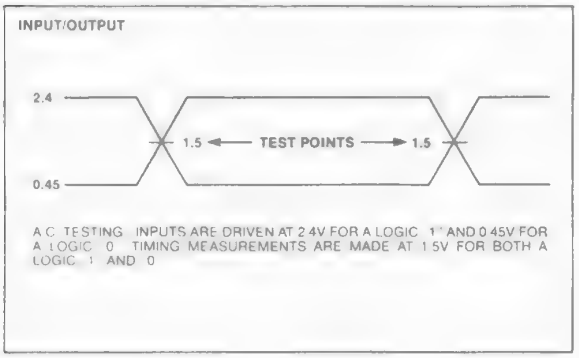
A.C. CHARACTERISTICS (Continued)

TIMING RESPONSES

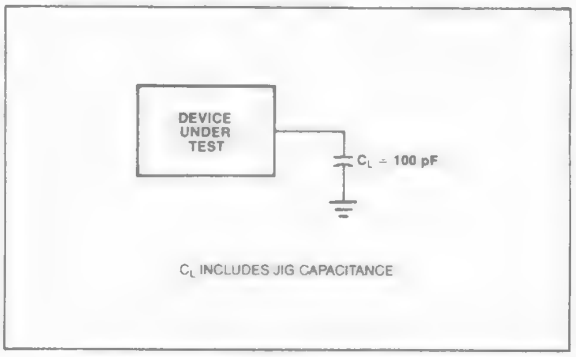
Symbol	Parameter	8086		8086-1 (Preliminary)		8086-2		Units	Test Conditions
		Min.	Max.	Min.	Max.	Min.	Max.		
TCLAV	Address Valid Delay	10	110	10	50	10	60	ns	*C_L = 20-100 pF for all 8086 Outputs (In addition to 8086 self-load)
TCLAX	Address Hold Time	10		10		10		ns	
TCLAZ	Address Float Delay	TCLAX	[illegible]	10	40	TCLAX	[illegible]	ns	
TLHLL	ALE Width	TCLCH−20		TCLCH−10		TCLCH-10		ns	
TCLLH	ALE Active Delay		[illegible]		40		[illegible]	ns	
TCHLL	ALE Inactive Delay		85		45		55	ns	
TLLAX	Address Hold Time to ALE Inactive	TCHCL−10		TCHCL−10		TCHCL−10		ns	
TCLDV	Data Valid Delay	10	110	10	50	10	60	ns	
TCHDX	Data Hold Time	10		10		10		[illegible]	
TWHDX	Data Hold Time After WR	TCLCH−30		TCLCH−25		TCLCH−30		ns	
TCVCTV	Control Active Delay 1	10	110	10	50	10	70	ns	
TCHCTV	Control Active Delay 2	10	110	10	45	10	60	ns	
TCVCTX	Control Inactive Delay	10	110	10	50	10	70	ns	
TAZRL	Address Float to READ Active	0		0		0		ns	
TCLRL	$\overline{RD}$ Active Delay	10	165	10	70	10	100	ns	
TCLRH	$\overline{RD}$ Inactive Delay	10	150	10	60	10	80	ns	
TRHAV	$\overline{RD}$ Inactive to Next Address Active	TCLCL−45		TCLCL−35		TCLCL−40		ns	
TCLHAV	HLDA Valid Delay	10	160	10	[illegible]	10	100	ns	
TRLRH	$\overline{RD}$ Width	2TCLCL−75		2TCLCL−40		2TCLCL−50		ns	
TWLWH	$\overline{WR}$ Width	2TCLCL−60		2TCLCL−35		2TCLCL−40		ns	
TAVAL	Address Valid to ALE Low	TCLCH−60		TCLCH−35		TCLCH−40		ns	
TOLOH	Output Rise Time		20		20		20	ns	From 0.8V to 2.0V
TOHOL	Output Fall Time		12		12		12	ns	From 2.0V to 0.8V

NOTES:
1. Signal at 8284A shown for reference only.
2. Setup requirement for asynchronous signal only to guarantee recognition at next CLK.
3. Applies only to T2 state. (8 ns into T3).

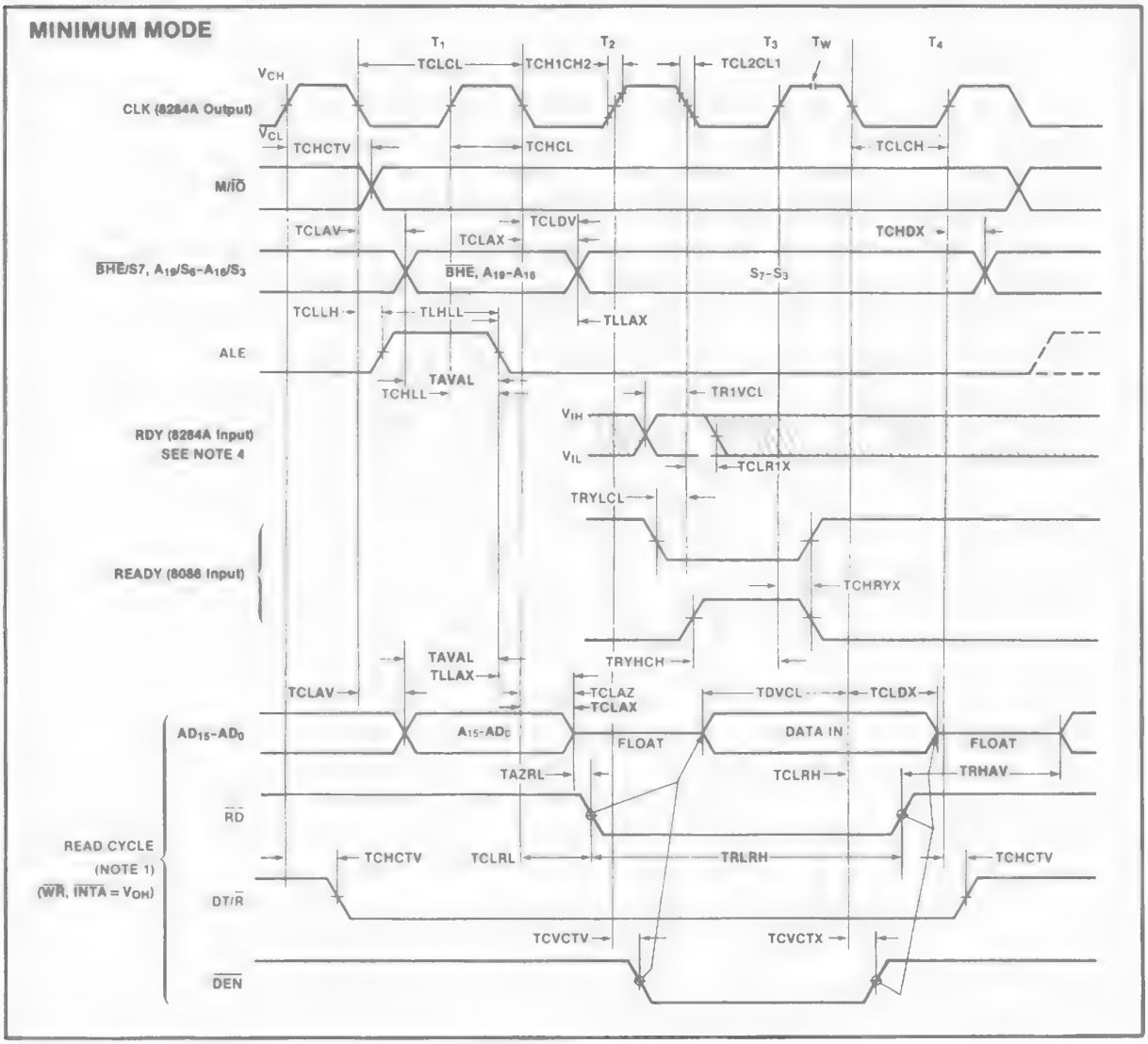
A.C. TESTING INPUT, OUTPUT WAVEFORM



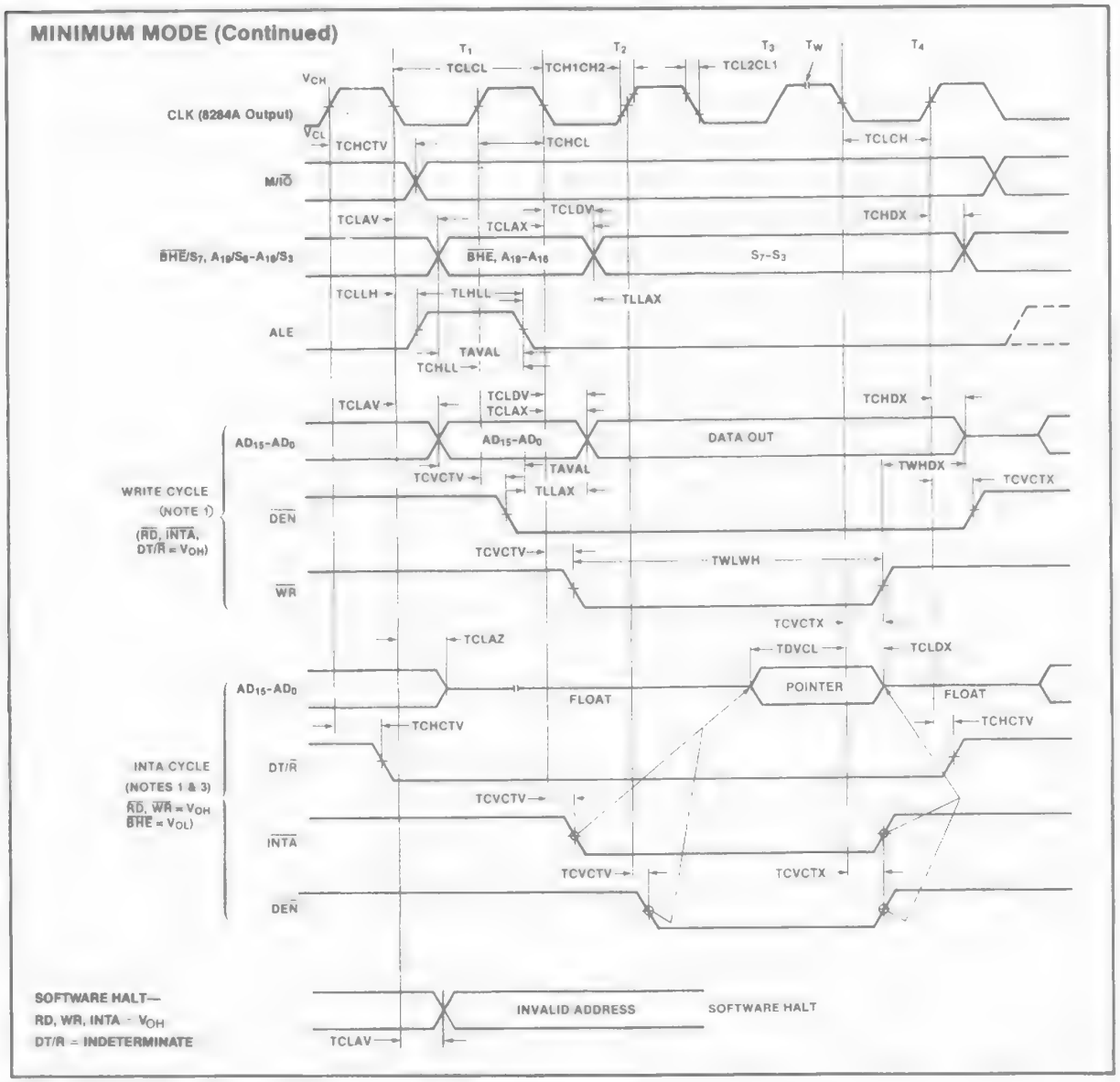
A.C. TESTING LOAD CIRCUIT



WAVEFORMS



WAVEFORMS (Continued)



NOTES:

1. All signals switch between V_{OH} and V_{OL} unless otherwise specified.
2. RDY is sampled near the end of T_2, T_3, T_W to determine if T_W machines states are to be inserted.
3. Two INTA cycles run back-to-back. The 8086 LOCAL ADDR/DATA BUS is floating during both INTA cycles. Control signals shown for second INTA cycle.
4. Signals at 8284A are shown for reference only.
5. All timing measurements are made at 1.5V unless otherwise noted.

A.C. CHARACTERISTICS

MAX MODE SYSTEM (USING 8288 BUS CONTROLLER) TIMING REQUIREMENTS

Symbol	Parameter	8086		8086-1 (Preliminary)		8086-2 (Preliminary)		Units	Test Conditions
		Min.	Max.	Min.	Max.	Min.	Max.		
TCLCL	CLK Cycle Period	200	500	100	500	125	500	ns	
TCLCH	CLK Low Time	118		53		[illegible]		ns	
TCHCL	CLK High Time	69		39		44		ns	
TCH1CH2	CLK Rise Time		10		10		10	ns	From 1.0V to 3.5V
TCL2CL1	CLK Fall Time		10		10		10	ns	From 3.5V to 1.0V
TDVCL	Data In Setup Time	30		5		20		[illegible]	
TCLDX	Data In Hold Time	10		10		10		ns	
TR1VCL	RDY Setup Time into 8284A (See Notes 1, 2)	35		35		35		ns	
TCLR1X	RDY Hold Time into 8284A (See Notes 1, 2)	0		0		0		ns	
TRYHCH	READY Setup Time into 8086	118		53		68		ns	
TCHRYX	READY Hold Time into 8086	30		20		[illegible]		ns	
TRYLCL	READY Inactive to CLK (See Note 4)	−8		−10		−8		ns	
TINVCH	Setup Time for Recognition (INTR, NMI, $\overline{TEST}$) (See Note 2)	30		15		15		[illegible]	
TGVCH	$\overline{RQ}/\overline{GT}$ Setup Time	30		12		15		ns	
TCHGX	$\overline{RQ}$ Hold Time into 8086	40		20		30		ns	
TILIH	Input Rise Time (Except CLK)		20		20		20	ns	From 0.8V to 2.0V
TIHIL	Input Fall Time (Except CLK)		12		12		12	ns	From 2.0V to 0.8V

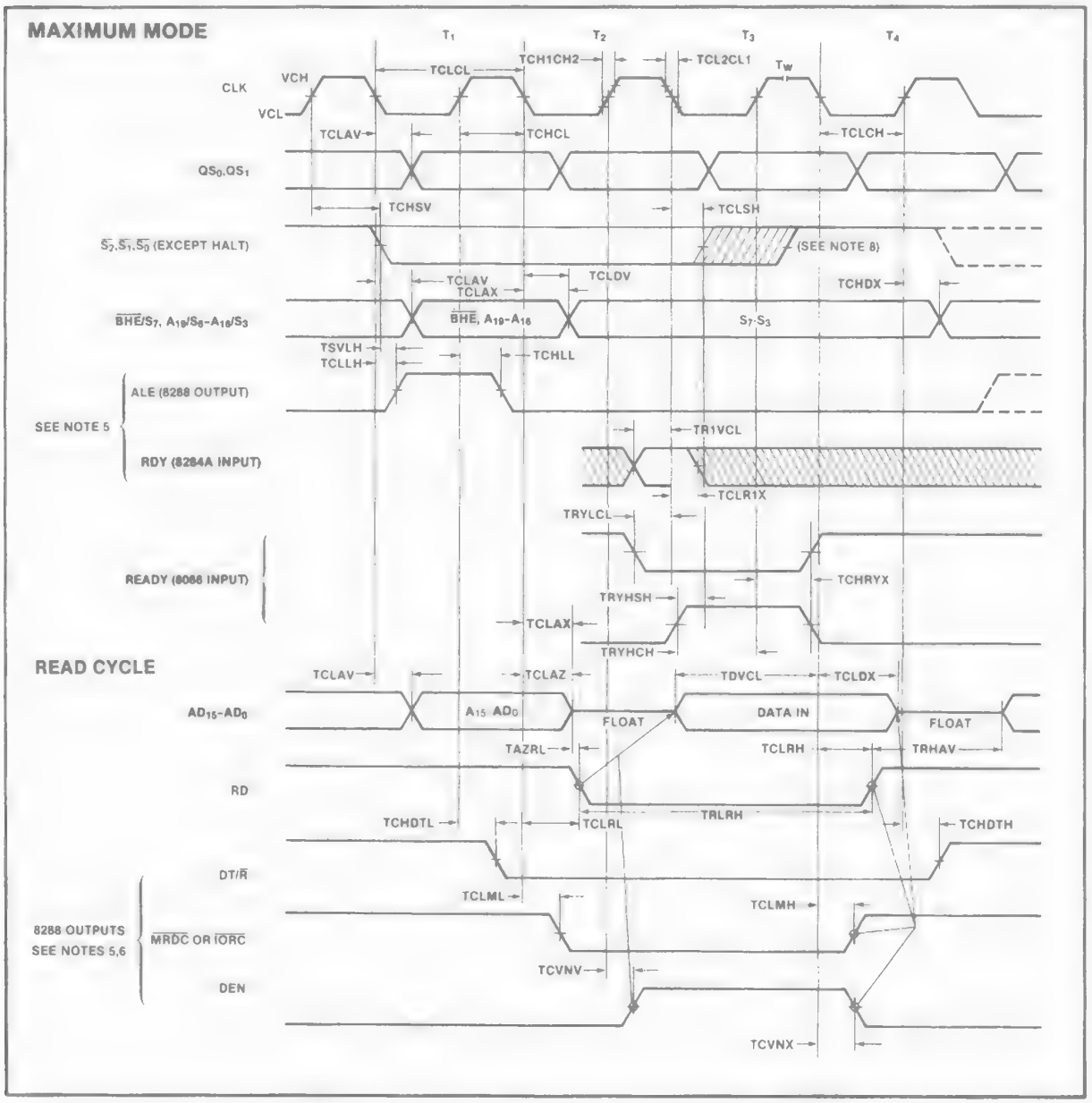
NOTES:
1. Signal at 8284A or 8288 shown for reference only.
2. Setup requirement for asynchronous signal only to guarantee recognition at next CLK.
3. Applies only to T3 and wait states.
4. Applies only to T2 state (8 ns into T3).

A.C. CHARACTERISTICS (Continued)

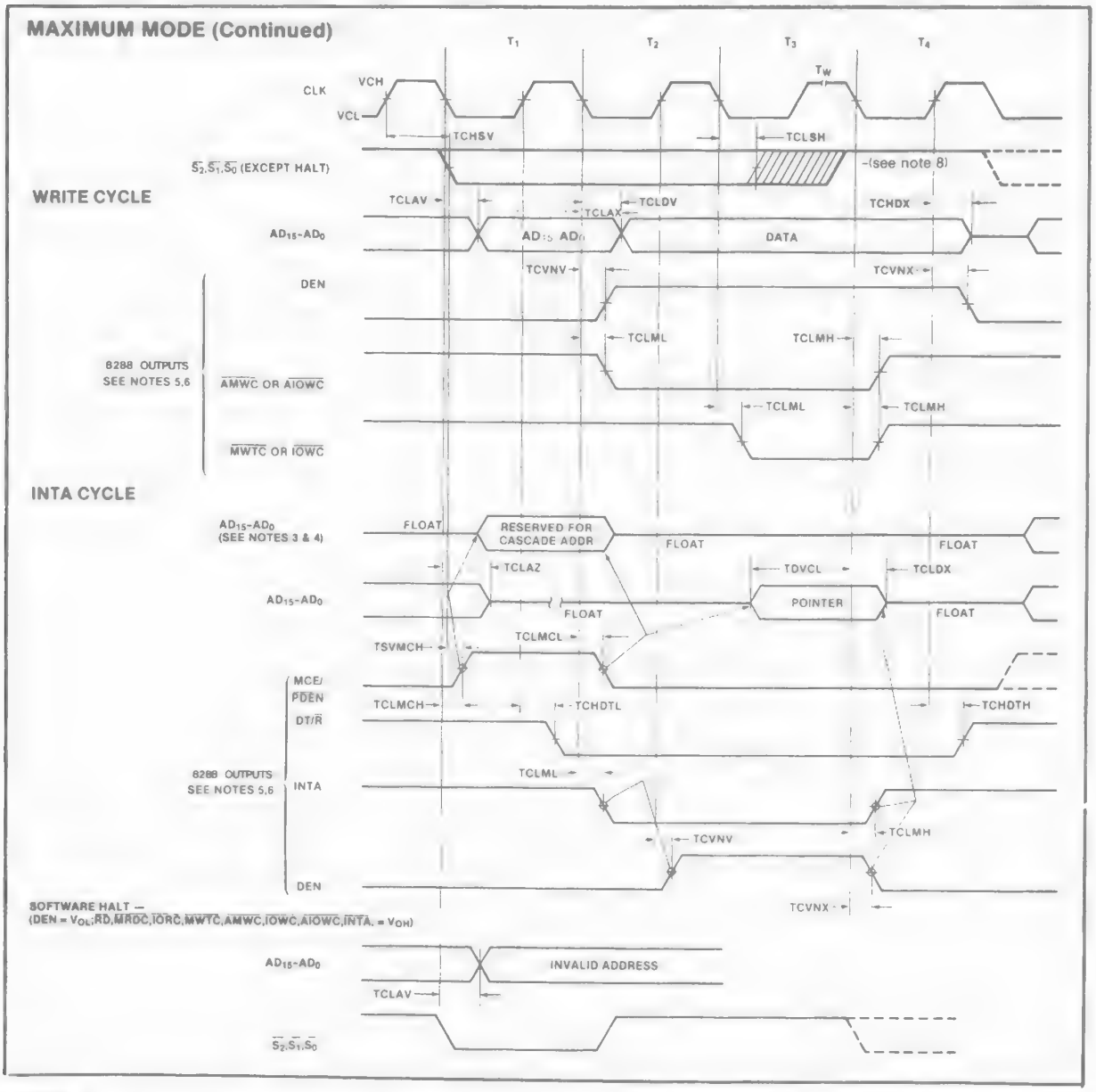
TIMING RESPONSES

Symbol	Parameter	8086		8086-1 (Preliminary)		8086-2 (Preliminary)		Units	Test Conditions
		Min.	Max.	Min.	Max.	Min.	Max.		
TCLML	Command Active Delay (See Note 1)	10	35	10	35	10	35	ns	
TCLMH	Command Inactive Delay (See Note 1)	10	35	10	35	10	35	ns	
TRYHSH	READY Active to Status Passive (See Note 3)		110		45		65	ns	
TCHSV	Status Active Delay	10	110	10	45	10	[illegible]	ns	
TCLSH	Status Inactive Delay	10	130	10	55	10	70	ns	
TCLAV	Address Valid Delay	10	110	10	50	10	60	ns	
TCLAX	Address Hold Time	10		10		10		ns	
TCLAZ	Address Float Delay	TCLAX	[illegible]	10	40	TCLAX	50	[illegible]	
TSVLH	Status Valid to ALE High (See Note 1)		15		15		15	ns	
TSVMCH	Status Valid to MCE High (See Note 1)		15		15		15	ns	
TCLLH	CLK Low to ALE Valid (See Note 1)		15		15		15	ns	
TCLMCH	CLK Low to MCE High (See Note 1)		15		15		15	ns	
TCHLL	ALE Inactive Delay (See Note 1)		15		15		15	ns	C_L = 20-100 pF for all 8086 Outputs (In addition to 8086 self-load)
TCLMCL	MCE Inactive Delay (See Note 1)		15		15		15	ns	
TCLDV	Data Valid Delay	10	110	10	[illegible]	10	[illegible]	[illegible]	
TCHDX	Data Hold Time	10		10		10		ns	
TCVNV	Control Active Delay (See Note 1)	5	45	5	45	5	45	ns	
TCVNX	Control Inactive Delay (See Note 1)	10	45	10	45	10	45	[illegible]	
TAZRL	Address Float to Read Active	0		0		0		ns	
TCLRL	RD Active Delay	10	165	10	70	10	100	[illegible]	
TCLRH	RD Inactive Delay	10	150	10	[illegible]	10	[illegible]	ns	
TRHAV	RD Inactive to Next Address Active	TCLCL−45		TCLCL−35		TCLCL−40		ns	
TCHDTL	Direction Control Active Delay (See Note 1)		50		[illegible]		50	[illegible]	
TCHDTH	Direction Control Inactive Delay (See Note 1)		[illegible]		[illegible]		[illegible]	ns	
TCLGL	GT Active Delay	0	[illegible]	0	45	0	[illegible]	[illegible]	
TCLGH	GT Inactive Delay	0	85	0	45	0	[illegible]	[illegible]	
TRLRH	RD Width	2TCLCL−75		2TCLCL−40		2TCLCL−50		ns	
TOLOH	Output Rise Time		[illegible]		[illegible]		[illegible]	ns	From 0.8V to 2.0V
TOHOL	Output Fall Time		12		12		12	[illegible]	From 2.0V to 0.8V

WAVEFORMS


MAXIMUM MODE
T1
T2
T3
T4
CLK
VCH
VCL
TCLCL
TCH1CH2
TCL2CL1
TW
TCLAV
TCHCL
TCLCH
QS0,QS1
TCHSV
TCLSH
S2,S1,S0 (EXCEPT HALT)
(SEE NOTE 8)
TCLAV
TCLAX
TCLDV
TCHDX
BHE/S7, A19/S6-A16/S3
BHE, A19-A16
S7-S3
TSVLH
TCLLH
TCHLL
ALE (8288 OUTPUT)
SEE NOTE 5
TR1VCL
RDY (8284A INPUT)
TCLR1X
TRYLCL
READY (8086 INPUT)
TCHRYX
TRYHSH
TCLAX
TRYHCH
READ CYCLE
TCLAV
TCLAZ
TDVCL
TCLDX
AD15-AD0
A15-AD0
FLOAT
DATA IN
FLOAT
TAZRL
TCLRH
TRHAV
RD
TCHDTL
TCLRL
TRLRH
TCHDTH
DT/R
TCLML
TCLMH
8288 OUTPUTS
SEE NOTES 5,6
MRDC OR IORC
TCVNV
DEN
TCVNX

WAVEFORMS (Continued)

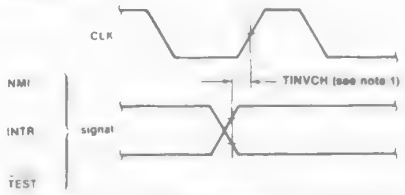


NOTES:

1. All signals switch between V_{OH} and V_{OL} unless otherwise specified.
2. RDY is sampled near the end of T_2, T_3, T_W to determine if T_W machines states are to be inserted.
3. Cascade address is valid between first and second INTA cycle.
4. Two INTA cycles run back-to-back. The 8086 LOCAL ADDR/DATA BUS is floating during both INTA cycles. Control for pointer address is shown for second INTA cycle.
5. Signals at 8284A or 8288 are shown for reference only.
6. The issuance of the 8288 command and control signals ($\overline{MRDC}$, $\overline{MWTC}$, $\overline{AMWC}$, $\overline{IORC}$, $\overline{IOWC}$, $\overline{AIOWC}$, $\overline{INTA}$ and DEN) lags the active high 8288 CEN.
7. All timing measurements are made at 1.5V unless otherwise noted.
8. Status inactive in state just prior to T_4.

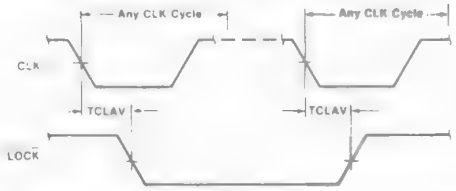
WAVEFORMS (Continued)

ASYNCHRONOUS SIGNAL RECOGNITION

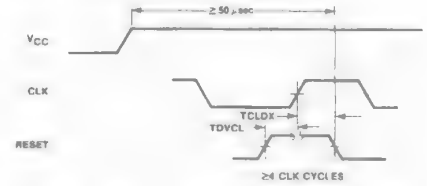


NOTE: 1 SETUP REQUIREMENTS FOR ASYNCHRONOUS SIGNALS ONLY TO GUARANTEE RECOGNITION AT NEXT CLK

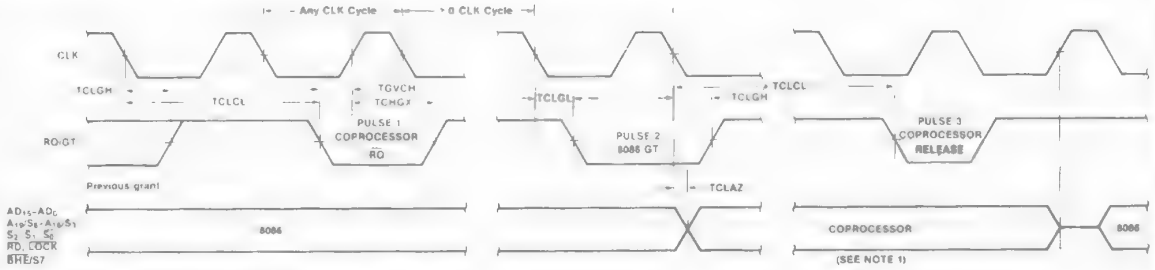
BUS LOCK SIGNAL TIMING (MAXIMUM MODE ONLY)



RESET TIMING



REQUEST/GRANT SEQUENCE TIMING (MAXIMUM MODE ONLY)



NOTES 1 THE COPROCESSOR MAY NOT DRIVE THE BUSES OUTSIDE THE REGION SHOWN WITHOUT RISKING CONTENTION

HOLD/HOLD ACKNOWLEDGE TIMING (MINIMUM MODE ONLY)

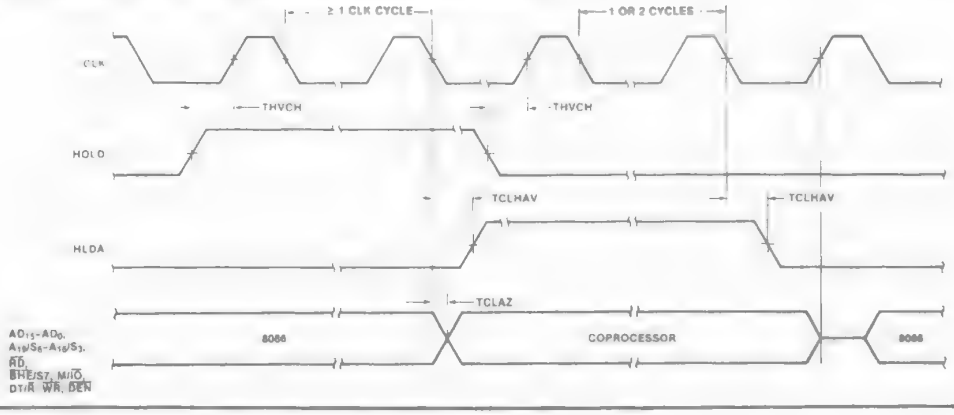


Table 2. Instruction Set Summary

	76543210	76543210	76543210	76543210
DATA TRANSFER				
MOV = Move:				
Register/memory to/from register	100010dw	mod reg r/m		
Immediate to register/memory	1100011w	mod000r/m	data	data if w=1
Immediate to register	1011w reg	data	data if w=1	
Memory to accumulator	1010000w	addr-low	addr-high	
Accumulator to memory	1010001w	addr-low	addr-high	
Register/memory to segment register	10001110	mod0reg r/m		
Segment register to register/memory	10001100	mod0reg r/m		
PUSH = Push:				
Register/memory	11111111	mod110 r/m		
Register	01010 reg			
Segment register	000reg110			
POP = Pop:				
Register/memory	10001111	mod000 r/m		
Register	01011 reg			
Segment register	000reg111			
XCHG = Exchange:				
Register/memory with register	1000011w	mod reg r/m		
Register with accumulator	10010 reg			
IN=Input from:				
Fixed port	1110010w	port		
Variable port	1110110w			
OUT = Output to:				
Fixed port	1110011w	port		
Variable port	1110111w			
XLAT = Translate byte to AL	11010111			
LEA=Load EA to register	10001101	mod reg r/m		
LDS=Load pointer to DS	11000101	mod reg r/m		
LES=Load pointer to ES	11000100	mod reg r/m		
LAHF=Load AH with flags	10011111			
SAHF=Store AH into flags	10011110			
PUSHF=Push flags	10011100			
POPF=Pop flags	10011101			
ARITHMETIC				
ADD = Add:				
Reg./memory with register to either	000000dw	mod reg r/m		
Immediate to register/memory	100000sw	mod000r/m	data	data if s:w=01
Immediate to accumulator	0000010w	data	data if w=1	
ADC = Add with carry:				
Reg./memory with register to either	000100dw	mod reg r/m		
Immediate to register/memory	100000sw	mod010 r/m	data	data if s:w=01
Immediate to accumulator	0001010w	data	data if w=1	
INC = Increment:				
Register/memory	1111111w	mod000 r/m		
Register	01000 reg			
AAA=ASCII adjust for add	00110111			
DAA=Decimal adjust for add	00100111			
SUB = Subtract:				
Reg./memory and register to either	001010dw	mod reg r/m		
Immediate from register/memory	100000sw	mod101 r/m	data	data if s:w=01
Immediate from accumulator	0010110w	data	data if w=1	
SBB = Subtract with borrow:				
Reg./memory and register to either	000110dw	mod reg r/m		
Immediate from register/memory	100000sw	mod011 r/m	data	data if s:w=01
Immediate from accumulator	0001110w	data	data if w=1	
DEC = Decrement:				
Register/memory	1111111w	mod001 r/m		
Register	01001 reg			
NEG = Change sign	1111011w	mod011 r/m		
CMP = Compare:				
Register/memory and register	001110dw	mod reg r/m		
Immediate with register/memory	100000sw	mod111 r/m	data	data if s:w=01
Immediate with accumulator	0011110w	data	data if w=1	
AAS = ASCII adjust for subtract	00111111			
DAS = Decimal adjust for subtract	00101111			
MUL = Multiply (unsigned)	1111011w	mod100 r/m		
IMUL = Integer multiply (signed)	1111011w	mod101 r/m		
AAM = ASCII adjust for multiply	11010100	00001010		
DIV = Divide (unsigned)	1111011w	mod110 r/m		
IDIV = Integer divide (signed)	1111011w	mod111 r/m		
AAD = ASCII adjust for divide	11010101	00001010		
CBW = Convert byte to word	10011000			
CWD = Convert word to double word	10011001			
LOGIC				
NOT = Invert	1111011w	mod010 r/m		
SHL/SAL = Shift logical/arithmetic left	110100vw	mod100 r/m		
SHR = Shift logical right	110100vw	mod101 r/m		
SAR = Shift arithmetic right	110100vw	mod111 r/m		
ROL = Rotate left	110100vw	mod000 r/m		
ROR = Rotate right	110100vw	mod001 r/m		
RCL = Rotate through carry flag left	110100vw	mod010 r/m		
RCR = Rotate through carry right	110100vw	mod011 r/m		
AND = And:				
Reg./memory and register to either	001000dw	mod reg r/m		
Immediate to register/memory	1000000w	mod100 r/m	data	data if w=1
Immediate to accumulator	0010010w	data	data if w=1	
TEST = And function to flags, no result:				
Register/memory and register	1000010w	mod reg r/m		
Immediate data and register/memory	1111011w	mod000 r/m	data	data if w=1
Immediate data and accumulator	1010100w	data	data if w=1	
OR = Or:				
Reg./memory and register to either	000010dw	mod reg r/m		
Immediate to register/memory	1000000w	mod001 r/m	data	data if w=1
Immediate to accumulator	0000110w	data	data if w=1	
XOR = Exclusive or:				
Reg./memory and register to either	001100dw	mod reg r/m		
Immediate to register/memory	1000000w	mod110 r/m	data	data if w=1
Immediate to accumulator	0011010w	data	data if w=1	
STRING MANIPULATION				
REP=Repeat	1111001z			
MOVS=Move byte/word	1010010w			
CMPS=Compare byte/word	1010011w			
SCAS=Scan byte/word	1010111w			
LODS=Load byte/wd to AL/AX	1010110w			
STOS=Stor byte/wd from AL/A	1010101w			

Mnemonics ©Intel, 1978

Table 2. Instruction Set Summary (Continued)

CONTROL TRANSFER

CALL - Call:	76543210	76543210	76543210
Direct within segment	11101000	disp-low	disp-high
Indirect within segment	11111111	mod 010 r/m	
Direct intersegment	10011010	offset-low	offset-high
		seg-low	seg-high
Indirect intersegment	11111111	mod 011 r/m	

JMP - Unconditional Jump:			
Direct within segment	11101001	disp-low	disp-high
Direct within segment-short	11101011	disp	
Indirect within segment	11111111	mod 100 r/m	
Direct intersegment	11101010	offset-low	offset-high
		seg-low	seg-high
Indirect intersegment	11111111	mod 101 r/m	

RET - Return from CALL			
Within segment	11000011		
Within seg. adding immed to SP	11000010	data-low	data-high
Intersegment	11001011		
Intersegment adding immediate to SP	11001010	data-low	data-high

JE/JZ Jump on equal/zero	01110100	disp
JL/JNGE Jump on less/not greater or equal	01111100	disp
JLE/JNG=Jump on less or equal/not greater	01111110	disp
JB/JNAE Jump on below/not above or equal	01110010	disp
JBE/JNA=Jump on below or equal/not above	01110110	disp
JP/JPE -Jump on parity/parity even	01110010	disp
JO Jump on overflow	01110000	disp
JS Jump on sign	01110100	disp
JNE/JNZ Jump on not equal/not zero	01110101	disp
JNL/JGE Jump on not less/greater or equal	01111101	disp
JNLE/JG Jump on not less or equal/greater	01111111	disp

	76543210	76543210
JNB/JAE Jump on not below/above or equal	01110011	disp
JNBE/JA Jump on not below or equal/above	01110111	disp
JNP/JPO Jump on not par/par odd	01111011	disp
JNO Jump on not overflow	01110001	disp
JNS Jump on not sign	01111001	disp
LOOP Loop CX times	11100010	disp
LOOPZ/LOOPE Loop while zero/equal	11100001	disp
LOOPNZ/LOOPNE Loop while not zero/equal	11100000	disp
JCXZ Jump on CX zero	11100011	disp

INT - Interrupt		
Type specified	11001101	type
Type 3	11001100	
INTO Interrupt on overflow	11001110	
IRET Interrupt return	11001111	

PROCESSOR CONTROL

CLC Clear carry	11111000
CMC Complement carry	11110101
STC Set carry	11111001
CLD Clear direction	11111100
STD Set direction	11111101
CLI Clear interrupt	11111010
STI Set interrupt	11111011
HLT Halt	11110100
WAIT Wait	10011011
ESC Escape to external device	11011xxx mod x x x r/m
LOCK Bus lock prefix	11110000

Footnotes:

AL = 8-bit accumulator
AX = 16-bit accumulator
CX = Count register
DS = Data segment
ES = Extra segment
Above/below refers to unsigned value
Greater = more positive;
Less = less positive (more negative) signed values
if d = 1 then "to" reg; if d = 0 then "from" reg
if w = 1 then word instruction; if w = 0 then byte instruction

if mod = 11 then r/m is treated as a REG field
if mod = 00 then DISP = 0*, disp-low and disp-high are absent
if mod = 01 then DISP = disp-low sign-extended to 16-bits, disp-high is absent
if mod = 10 then DISP = disp-high: disp-low
if r/m = 000 then EA = (BX) + (SI) + DISP
if r/m = 001 then EA = (BX) + (DI) + DISP
if r/m = 010 then EA = (BP) + (SI) + DISP
if r/m = 011 then EA = (BP) + (DI) + DISP
if r/m = 100 then EA = (SI) + DISP
if r/m = 101 then EA = (DI) + DISP
if r/m = 110 then EA = (BP) + DISP*
if r/m = 111 then EA = (BX) + DISP
DISP follows 2nd byte of instruction (before data if required)

*except if mod = 00 and r/m = 110 then EA = disp-high: disp-low

if s:w = 01 then 16 bits of immediate data form the operand.
if s:w = 11 then an immediate data byte is sign extended to form the 16-bit operand
if v = 0 then "count" = 1; if v = 1 then "count" in (CL)
x = don't care
z is used for string primitives for comparison with ZF FLAG.

SEGMENT OVERRIDE PREFIX

0 0 1 reg 1 1 0

REG is assigned according to the following table:

16-Bit (w = 1)	8-Bit (w = 0)	Segment
000 AX	000 AL	00 ES
001 CX	001 CL	01 CS
010 DX	010 DL	10 SS
011 BX	011 BL	11 DS
100 SP	100 AH	
101 BP	101 CH	
110 SI	110 DH	
111 DI	111 [illegible]	

Instructions which reference the flag register file as a 16-bit object use the symbol FLAGS to represent the file:

FLAGS = X:X:X:X:(OF):(DF):(IF):(TF):(SF):(ZF):X:(AF):X:(PF):X:(CF)

Mnemonics © Intel, 1978

PRELIMINARY

iAPX 186
HIGH INTEGRATION 16-BIT MICROPROCESSOR

- Integrated Feature Set
  - —Enhanced 8086-2 CPU
  - —Clock Generator
  - —2 Independent, High-Speed DMA Channels
  - —Programmable Interrupt Controller
  - —3 Programmable 16-bit Timers
  - —Programmable Memory and Peripheral Chip-Select Logic
  - —Programmable Wait State Generator
  - —Local Bus Controller
- High-Performance 8 MHz Processor
  - —2 Times the Performance of the Standard iAPX 86
  - —4 MByte/Sec Bus Bandwidth Interface
- Direct Addressing Capability to 1 MByte of Memory
- Completely Object Code Compatible with All Existing iAPX 86, 88 Software
  - —10 New Instruction Types
- Compatible with 8282/83/86/87, 8288, 8289 Bus Support Components
- Complete System Development Support
  - —Development Software: Assembler, PL/M, Pascal, Fortran, and System Utilities
  - —In-Circuit-Emulator (I²ICE™-186)
  - —iRMX™ 86, 88 Compatible (80130 OSF)
- Optional Numeric Processor Extension
  - —iAPX 186/20 High-Performance 80-bit Numeric Data Processor

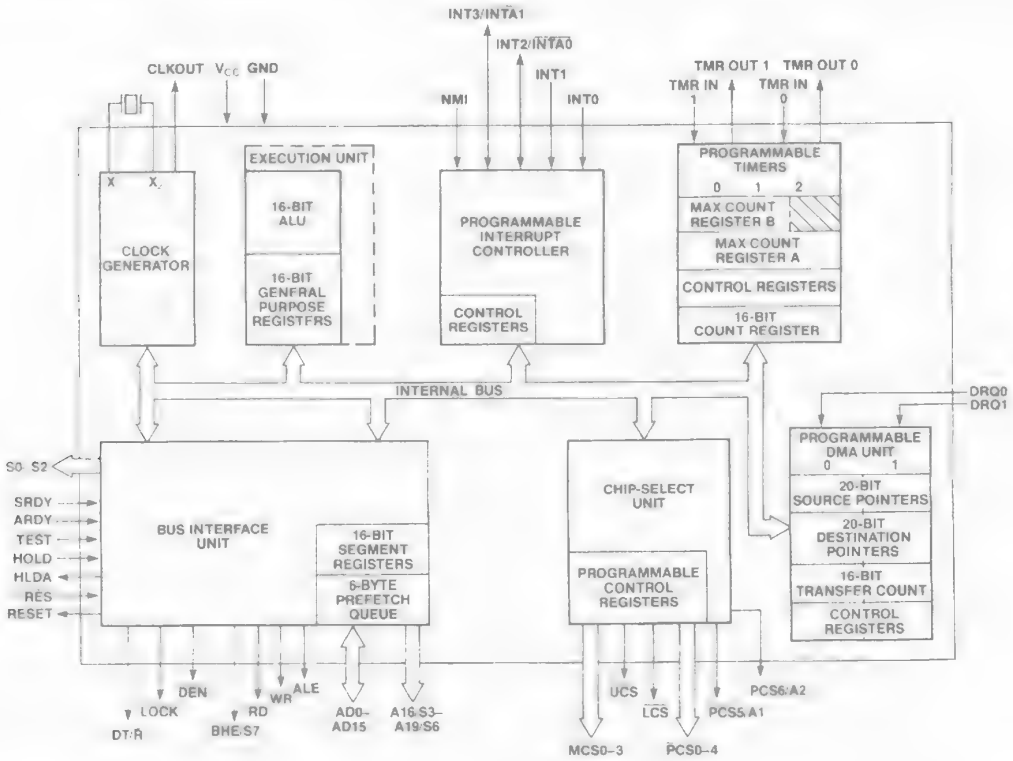


Figure 1. iAPX 186 Block Diagram

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DECEMBER 1982
ORDER NUMBER: 210451-002

The Intel iAPX 186 (80186 part number) is a highly integrated 16-bit microprocessor. The iAPX 186 effectively combines 15–20 of the most common iAPX 86 system components onto one. The 80186 provides two times greater throughput than the standard 5 MHz iAPX 86. The iAPX 186 is upward compatible with iAPX 86 and 88 software and adds 10 new instruction types to the existing set.

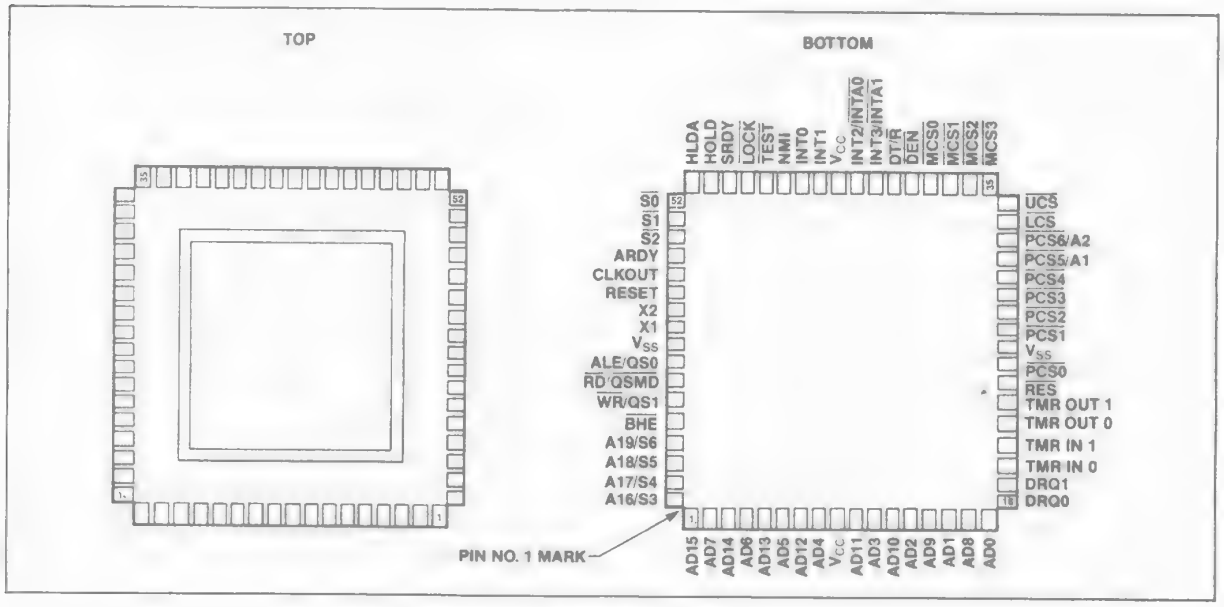

Figure 2. 80186 Pinout Diagram

Table 1. 80186 Pin Description

Symbol	Pin No.	Type	Name and Function
V_{CC}, V_{CC}	9,43	I	System Power: +5 volt power supply.
V_{SS}, V_{SS}	26,60	I	System Ground.
RESET	57	O	Reset Output indicates that the 80186 CPU is being reset, and can be used as a system reset. It is active HIGH, synchronized with the processor clock, and lasts an integer number of clock periods corresponding to the length of the $\overline{RES}$ signal.
X1, X2	59,58	I	Crystal Inputs, X1 and X2, provide an external connection for a fundamental mode parallel resonant crystal for the internal crystal oscillator. X1 can interface to an external clock instead of a crystal. The input or oscillator frequency is internally divided by two to generate the clock signal (CLKOUT).
CLKOUT	56	O	Clock Output provides the system with a 50% duty cycle waveform. All device pin timings are specified relative to CLKOUT. CLKOUT has sufficient MOS drive capabilities for the 8087 Numeric Processor Extension.
$\overline{RES}$	24	I	System Reset causes the 80186 to immediately terminate its present activity, clear the internal logic, and enter a dormant state. This signal may be asynchronous to the 80186 clock. The 80186 begins fetching instructions approximately 7 clock cycles after $\overline{RES}$ is returned HIGH. $\overline{RES}$ is required to be LOW for greater than 4 clock cycles and is internally synchronized. For proper initialization, the LOW-to-HIGH transition of $\overline{RES}$ must occur no sooner than 50 microseconds after power up. This input is provided with a Schmitt-trigger to facilitate power-on $\overline{RES}$ generation via an RC network. When $\overline{RES}$ occurs, the 80188 will drive the status lines to an inactive level for one clock, and then tri-state them.

Table 1. 80186 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{TEST}$	47	I	$\overline{TEST}$ is examined by the WAIT instruction. If the $\overline{TEST}$ input is HIGH when "WAIT" execution begins, instruction execution will suspend. $\overline{TEST}$ will be resampled until it goes LOW, at which time execution will resume. If interrupts are enabled while the 80186 is waiting for $\overline{TEST}$, interrupts will be serviced. This input is synchronized internally.
TMR IN 0, TMR IN1	20 21	I I	Timer Inputs are used either as clock or control signals, depending upon the programmed timer mode. These inputs are active HIGH (or LOW-to-HIGH transitions are counted) and internally synchronized.
TMR OUT 0, TMR OUT 1	22 23	O O	Timer outputs are used to provide single pulse or continuous waveform generation, depending upon the timer mode selected.
DRQ0 DRQ1	18 19	I I	DMA Request is driven HIGH by an external device when it desires that a DMA channel (Channel 0 or 1) perform a transfer. These signals are active HIGH, level-triggered, and internally synchronized.
NMI	46	I	Non-Maskable Interrupt is an edge-triggered input which causes a type 2 interrupt. NMI is not maskable internally. A transition from a LOW to HIGH initiates the interrupt at the next instruction boundary. NMI is latched internally. An NMI duration of one clock or more will guarantee service. This input is internally synchronized.
INT0, INT1, INT2/$\overline{INTA0}$ INT3/$\overline{INTA1}$	45,44 42 41	I I/O I/O	Maskable Interrupt Requests can be requested by strobing one of these pins. When configured as inputs, these pins are active HIGH. Interrupt Requests are synchronized internally. INT2 and INT3 may be configured via software to provide active-LOW interrupt-acknowledge output signals. All interrupt inputs may be configured via software to be either edge- or level-triggered. To ensure recognition, all interrupt requests must remain active until the interrupt is acknowleged. When iRMX mode is selected, the function of these pins changes (see Interrupt Controller section of this data sheet).
A19/S6, A18/S5, A17/S4, A16/S3	65–68	O O O O	Address Bus Outputs (16–19) and Bus Cycle Status (3–6) reflect the four most significant address bits during T_1. These signals are active HIGH. During T_2, T_3, T_W, and T_4, status information is available on these lines as encoded below: | | Low | High | | S6 | Processor Cycle | DMA Cycle | S3,S4, and S5 are defined as LOW during T_2–T_4.
AD15–AD0	10–17, 1–8	I/O	Address/Data Bus (0–15) signals constitute the time mutiplexed memory or I/O address (T_1) and data (T_2, T_3, T_W, and T_4) bus. The bus is active HIGH. A_0 is analogous to $\overline{BHE}$ for the lower byte of the data bus, pins D_7 through D_0. It is LOW during T_1 when a byte is to be transferred onto the lower portion of the bus in memory or I/O operations.
$\overline{BHE}$/S7	64	O	During T_1 the Bus High Enable signal should be used to determine if data is to be enabled onto the most significant half of the data bus, pins D_{15}–D_8. $\overline{BHE}$ is LOW during T_1 for read, write, and interrupt acknowledge cycles when a byte is to be transferred on the higher half of the bus. The S_7 status information is available during T_2, T_3, and T_4. S_7 is logically equivalent to $\overline{BHE}$. The signal is active LOW, and is tristated OFF during bus HOLD. $\overline{BHE}$ and A0 Encodings | $\overline{BHE}$ Value | A0 Value | Function | | 0 | 0 | Word Transfer | | 0 | 1 | Byte Transfer on upper half of data bus (D15–D8) | | 1 | 0 | Byte Transfer on lower half of data bus (D_7–D_0) | | 1 | 1 | Reserved |

Table 1. 80186 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
ALE/QS0	61	O	Address Latch Enable/Queue Status 0 is provided by the 80186 to latch the address into the 8282/8283 address latches. ALE is active HIGH. Addresses are guaranteed to be valid on the trailing edge of ALE. The ALE rising edge is generated off the rising edge of the CLKOUT immediately preceding T_1 of the associated bus cycle, effectively one-half clock cycle earlier than in the standard 8086. The trailing edge is generated off the CLKOUT rising edge in T_1 as in the 8086. Note that ALE is never floated.
$\overline{WR}$/QS1	63	O	Write Strobe/Queue Status 1 indicates that the data on the bus is to be written into a memory or an I/O device. $\overline{WR}$ is active for T_2, T_3, and T_W of any write cycle. It is active LOW, and floats during "HOLD." It is driven HIGH for one clock during Reset, and then floated. When the 80186 is in queue status mode, the ALE/QS0 and $\overline{WR}$/QS1 pins provide information about processor/instruction queue interaction. QS1 / QS0 / Queue Operation 0 / 0 / No queue operation 0 / 1 / First opcode byte fetched from the queue 1 / 1 / Subsequent byte fetched from the queue 1 / 0 / Empty the queue
$\overline{RD}$/$\overline{QSMD}$	62	O	Read Strobe indicates that the 80186 is performing a memory or I/O read cycle. $\overline{RD}$ is active LOW for T_2, T_3, and T_W of any read cycle. It is guaranteed not to go LOW in T_2 until after the Address Bus is floated. $\overline{RD}$ is active LOW, and floats during "HOLD." $\overline{RD}$ is driven HIGH for one clock during Reset, and then the output driver is floated. A weak internal pull-up mechanism on the $\overline{RD}$ line hols it HIGH when the line is not driven. During RESET the pin is sampled to determine whether the 80186 should provide ALE, $\overline{WR}$, and $\overline{RD}$, or if the Queue-Status should be provided. $\overline{RD}$ should be connected to GND to provide Queue-Status data.
ARDY	55	I	Asynchronous Ready informs the 80186 that the addressed memory space or I/O device will complete a data transfer. The ARDY input pin will accept an asynchronous input, and is active HIGH. Only the rising edge is internally synchronized by the 80186. This means that the falling edge of ARDY must be synchronized to the 80186 clock. If connected to V_{CC}, no WAIT states are inserted. Asynchronous ready (ARDY) or synchronous ready (SRDY) must be active to terminate a bus cycle.
SRDY	49	I	Synchronous Ready must be synchronized externally to the 80186. The use of SRDY provides a relaxed system-timing specification on the Ready input. This is accomplished by eliminating the one-half clock cycle which is required for internally resolving the signal level when using the ARDY input. This line is active HIGH. If this line is connected to V_{CC}, no WAIT states are inserted. Asynchronous ready (ARDY) or synchronous ready (SRDY) must be active before a bus cycle is terminated. If unused, this line should be tied LOW.
$\overline{LOCK}$	48	O	$\overline{LOCK}$ output indicates that other system bus masters are not to gain control of the system bus while $\overline{LOCK}$ is active LOW. The $\overline{LOCK}$ signal is requested by the LOCK prefix instruction and is activated at the beginning of the first data cycle associated with the instruction following the LOCK prefix. It remains active until the completion of the instruction following the LOCK prefix. No prefetches will occur while $\overline{LOCK}$ is asserted. $\overline{LOCK}$ is active LOW, is driven HIGH for one clock during RESET, and then floated. If unused, this line should be tied LOW.

Table 1. 80186 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{S0}$,$\overline{S1}$,$\overline{S2}$	52–54	O	Bus cycle status $\overline{S0}$–$\overline{S2}$ are encoded to provide bus-transaction information: 80186 Bus Cycle Status Information $\overline{S2}$ / $\overline{S1}$ / $\overline{S0}$ / Bus Cycle Initiated 0 0 0 Interrupt Acknowledge 0 0 1 Read I/O 0 1 0 Write I/O 0 1 1 Halt 1 0 0 Instruction Fetch 1 0 1 Read Data from Memory 1 1 0 Write Data to Memory 1 1 1 Passive (no bus cycle) The status pins float during "HOLD." $\overline{S2}$ may be used as a logical M/$\overline{IO}$ indicator, and $\overline{S1}$ as a DT/$\overline{R}$ indicator. The status lines are driven HIGH for one clock during Reset, and then floated until a bus cycle begins.
HOLD (input) HLDA (output)	50 51	I O	HOLD indicates that another bus master is requesting the local bus. The HOLD input is active HIGH. HOLD may be asynchronous with respect to the 80186 clock. The 80186 will issue a HLDA in response to a HOLD request at the end of T_4 or T_I. Simultaneous with the issuance of HLDA, the 80186 will float the local bus and control lines. After HOLD is detected as being LOW, the 80186 will lower HLDA. When the 80186 needs to run another bus cycle, it will again drive the local bus and control lines.
$\overline{UCS}$	34	O	Upper Memory Chip Select is an active LOW output whenever a memory reference is made to the defined upper portion (1K–256K block) of memory. This line is not floated during bus HOLD. The address range activating $\overline{UCS}$ is software programmable.
$\overline{LCS}$	33	O	Lower Memory Chip Select is active LOW whenever a memory reference is made to the defined lower portion (1K–256K) of memory. This line is not floated during bus HOLD. The address range activating $\overline{LCS}$ is software programmable.
$\overline{MCS0}$–3	38,37,36,35	O	Mid-Range Memory Chip Select signals are active LOW when a memory reference is made to the defined mid-range portion of memory (8K–512K). These lines are not floated during bus HOLD. The address ranges activating $\overline{MCS0}$–3 are software programmable.
$\overline{PCS0}$–4	25,27–30	O	Peripheral Chip Select signals 0–4 are active LOW when a reference is made to the defined peripheral area (64K byte I/O space). These lines are not floated during bus HOLD. The address ranges activating $\overline{PCS0}$–4 are software programmable.
$\overline{PCS5}$/A1	31	O	Peripheral Chip Select 5 or Latched A1 may be programmed to provide a sixth peripheral chip select, or to provide an internally latched A1 signal. The address range activating $\overline{PCS5}$ is software programmable. When programmed to provide latched A1, rather than $\overline{PCS5}$, this pin will retain the previously latched value of A1 during a bus HOLD. A1 is active HIGH.
$\overline{PCS6}$/A2	32	O	Peripheral Chip Select 6 or Latched A2 may be programmed to provide a seventh peripheral chip select, or to provide an internally latched A2 signal. The address range activating $\overline{PCS6}$ is software programmable. When programmed to provide latched A2, rather than $\overline{PCS6}$, this pin will retain the previously latched value of A2 during a bus HOLD. A2 is active HIGH.
DT/$\overline{R}$	40	O	Data Transmit/Receive controls the direction of data flow through the external 8286/8287 data bus transceiver. When LOW, data is transferred to the 80186. When HIGH the 80186 places write data on the data bus.
$\overline{DEN}$	39	O	Data Enable is provided as an 8286/8287 data bus transceiver output enable. $\overline{DEN}$ is active LOW during each memory and I/O access. $\overline{DEN}$ is HIGH whenever DT/$\overline{R}$ changes state.

FUNCTIONAL DESCRIPTION

Introduction

The following Functional Description describes the base architecture of the iAPX 186. This architecture is common to the iAPX 86, 88, and 286 microprocessor families as well. The iAPX 186 is a very high integration 16-bit microprocessor. It combines 15–20 of the most common microprocessor system components onto one chip while providing twice the performance of the standard iAPX 86. The 80186 is object code compatible with the iAPX 86, 88 microprocessors and adds 10 new instruction types to the existing iAPX 86, 88 instruction set.

iAPX 186 BASE ARCHITECTURE

The iAPX 86, 88, 186, and 286 family all contain the same basic set of registers, instructions, and addressing modes. The 80186 processor is upward compatible with the 8086, 8088, and 80286 CPUs.

Register Set

The 80186 base architecture has fourteen registers as shown in Figures 3a and 3b. These registers are grouped into the following categories.

General Registers
Eight 16-bit general purpose registers used to contain arithmetic and logical operands. Four of these (AX, BX, CX, and DX) can be used as 16-bit registers or split into pairs of separate 8-bit registers.

Segment Registers
Four 16-bit special purpose registers select, at any given time, the segments of memory that are immediately addressable for code, stack, and data. (For usage, refer to Memory Organization.)

Base and Index Registers
Four of the general purpose registers may also be used to determine offset addresses of operands in memory. These registers may contain base addresses or indexes to particular locations within a segment. The addressing mode selects the specific registers for operand and address calculations.

Status and Control Registers
Two 16-bit special purpose registers record or alter certain aspects of the 80186 processor state. These are the Instruction Pointer Register, which contains the offset address of the next sequential instruction to be executed, and the Status Word Register, which contains status and control flag bits (see Figures 3a and 3b).

Status Word Description

The Status Word records specific characteristics of the result of logical and arithmetic instructions (bits 0, 2, 4, 6, 7, and 11) and controls the operation of the 80186 within a given operating mode (bits 8, 9, and 10). The Status Word Register is 16-bits wide. The function of the Status Word bits is shown in Table 2.

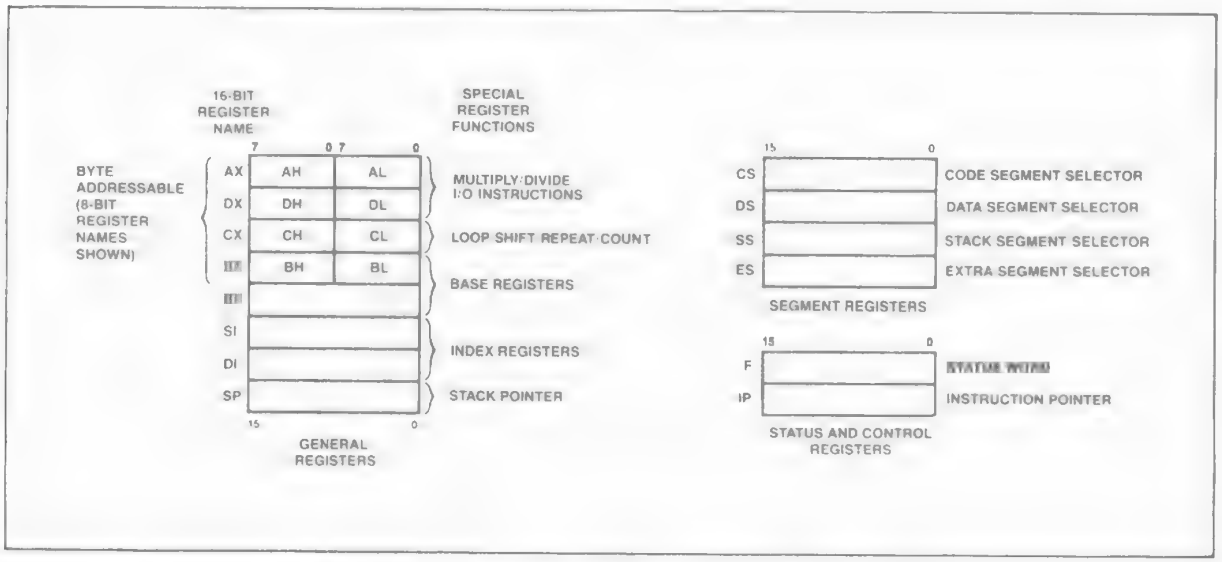

Figure 3a. 80186 General Purpose Register Set

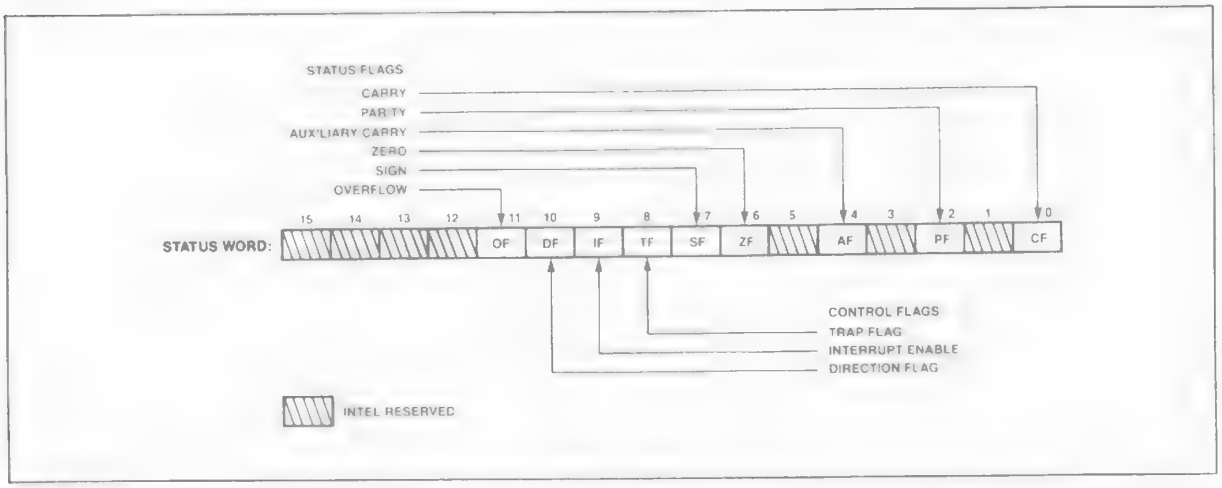

Figure 3b. Status Word Format

Table 2. Status Word Bit Functions

Bit Position	Name	Function
0	CF	Carry Flag—Set on high-order bit carry or borrow; cleared otherwise
2	PF	Parity Flag—Set if low-order 8 bits of result contain an even number of 1-bits; cleared otherwise
4	AF	Set on carry from or borrow to the low order four bits of AL; cleared otherwise
6	ZF	Zero Flag–Set if result is zero; cleared otherwise
7	SF	Sign Flag—Set equal to high-order bit of result (0 if positive, 1 if negative)
8	TF	Single Step Flag—Once set, a single step interrupt occurs after the next instruction executes. TF is cleared by the single step interrupt.
9	IF	Interrupt-enable Flag—When set, maskable interrupts will cause the CPU to transfer control to an interrupt vector specified location.
10	DF	Direction Flag—Causes string instructions to auto decrement the appropriate index register when set. Clearing DF causes auto increment.
11	OF	Overflow Flag—Set if the signed result cannot be expressed within the number of bits in the destination operand; cleared otherwise

Instruction Set

The instruction set is divided into seven categories: data transfer, arithmetic, shift/rotate/logical, string manipulation, control transfer, high-level instructions, and processor control. These categories are summarized in Figure 4.

An 80186 instruction can reference anywhere from zero to several operands. An operand can reside in a register, in the instruction itself, or in memory. Specific operand addressing modes are discussed later in this data sheet.

Memory Organization

Memory is organized in sets of segments. Each segment is a linear contiguous sequence of up to 64K (2^{16}) 8-bit bytes. Memory is addressed using a two-component address (a pointer) that consists of a 16-bit base segment and a 16-bit offset. The 16-bit base values are contained in one of four internal segment registers (code, data, stack, extra). The physical address is calculated by shifting the base value LEFT by four bits and adding the 16-bit offset value to yield a 20-bit physical address (see Figure 5). This allows for a 1 MByte physical address size.

All instructions that address operands in memory must specify the base segment and the 16-bit offset value. For speed and compact instruction encoding, the segment register used for physical address generation is implied by the addressing mode used (see Table 3). These rules follow the way programs are written (see Figure 6) as independent modules that require areas for code and data, a stack, and access to external data areas.

Special segment override instruction prefixes allow the implicit segment register selection rules to be overridden for special cases. The stack, data, and extra segments may coincide for simple programs.

GENERAL PURPOSE	
MOV	Move byte or word
PUSH	Push word onto stack
POP	Pop word off stack
PUSHA	Push all registers on stack
POPA	Pop all registers from stack
XCHG	Exchange byte or word
XLAT	Translate byte
INPUT/OUTPUT	
IN	Input byte or word
OUT	Output byte or word
ADDRESS OBJECT	
LEA	Load effective address
LDS	Load pointer using DS
LES	Load pointer using ES
FLAG TRANSFER	
LAHF	Load AH register from flags
SAHF	Store AH register in flags
PUSHF	Push flags onto stack
POPF	Pop flags off stack

ADDITION	
ADD	Add byte or word
ADC	Add byte or word with carry
INC	Increment byte or word by 1
AAA	ASCII adjust for addition
DAA	Decimal adjust for addition
SUBTRACTION	
SUB	Subtract byte or word
SBB	Subtract byte or word with borrow
DEC	Decrement byte or word by 1
NEG	Negate byte or word
CMP	Compare byte or word
AAS	ASCII adjust for subtraction
DAS	Decimal adjust for subtraction
MULTIPLICATION	
MUL	Multiply byte or word unsigned
IMUL	Integer multiply byte or word
AAM	ASCII adjust for multiply
DIVISION	
DIV	Divide byte or word unsigned
IDIV	Integer divide byte or word
AAD	ASCII adjust for division
CBW	Convert byte to word
CWD	Convert word to doubleword

MOVS	Move byte or word string
INS	Input bytes or word string
OUTS	Output bytes or word string
CMPS	Compare byte or word string
SCAS	Scan byte or word string
LODS	Load byte or word string
STOS	Store byte or word string
REP	Repeat
REPE/REPZ	Repeat while equal/zero
REPNE/REPNZ	Repeat while not equal/not zero

LOGICALS	
NOT	"Not" byte or word
AND	"And" byte or word
OR	"Inclusive or" byte or word
XOR	"Exclusive or" byte or word
TEST	"Test" byte or word
SHIFTS	
SHL/SAL	Shift logical/arithmetic left byte or word
SHR	Shift logical right byte or word
SAR	Shift arithmetic right byte or word
ROTATES	
ROL	Rotate left byte or word
ROR	Rotate right byte or word
RCL	Rotate through carry left byte or word
RCR	Rotate through carry right byte or word

FLAG OPERATIONS	
STC	Set carry flag
CLC	Clear carry flag
CMC	Complement carry flag
STD	Set direction flag
CLD	Clear direction flag
STI	Set interrupt enable flag
CLI	Clear interrupt enable flag
EXTERNAL SYNCHRONIZATION	
HLT	Halt until interrupt or reset
WAIT	Wait for $\overline{\text{TEST}}$ pin active
ESC	Escape to extension processor
LOCK	Lock bus during next instruction
NO OPERATION	
NOP	No operation
HIGH LEVEL INSTRUCTIONS	
ENTER	Format stack for procedure entry
LEAVE	Restore stack for procedure exit
BOUND	Detects values outside prescribed range

Figure 4. iAPX 186 Instruction Set

CONDITIONAL TRANSFERS		UNCONDITIONAL TRANSFERS	
JA/JNBE	Jump if above/not below nor equal	CALL	Call procedure
JAE/JNB	Jump if above or equal/not below	RET	Return from procedure
JB/JNAE	Jump if below/not above nor equal	JMP	Jump
JBE/JNA	Jump if below or equal/not above		
JC	Jump if carry	**ITERATION CONTROLS**	
JE/JZ	Jump if equal/zero		
JG/JNLE	Jump if greater/not less nor equal	LOOP	Loop
JGE/JNL	Jump if greater or equal/not less	LOOPE/LOOPZ	Loop if equal/zero
JL/JNGE	Jump if less/not greater nor equal	LOOPNE/LOOPNZ	Loop if not equal/not zero
JLE/JNG	Jump if less or equal/not greater	JCXZ	Jump if register CX = 0
JNC	Jump if not carry		
JNE/JNZ	Jump if not equal/not zero	**INTERRUPTS**	
JNO	Jump if not overflow		
JNP/JPO	Jump if not parity/parity odd	INT	Interrupt
JNS	Jump if not sign	INTO	Interrupt if overflow
JO	Jump if overflow	IRET	Interrupt return
JP/JPE	Jump if parity/parity even		
JS	Jump if sign		

Figure 4. iAPX 186 Instruction Set (continued)

To access operands that do not reside in one of the four immediately available segments, a full 32-bit pointer can be used to reload both the base (segment) and offset values.

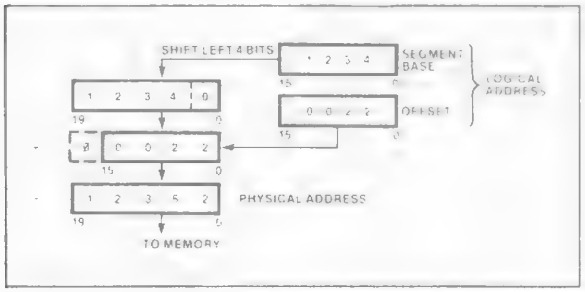

Figure 5. Two Component Address

Table 3. Segment Register Selection Rules

Memory Reference Needed	Segment Register Used	Implicit Segment Selection Rule
Instructions	Code (CS)	Instruction prefetch and immediate data.
Stack	Stack (SS)	All stack pushes and pops; any memory references which use BP Register as a base register.
External Data (Global)	Extra (ES)	All string instruction references which use the DI register as an index.
Local Data	Data (DS)	All other data references.

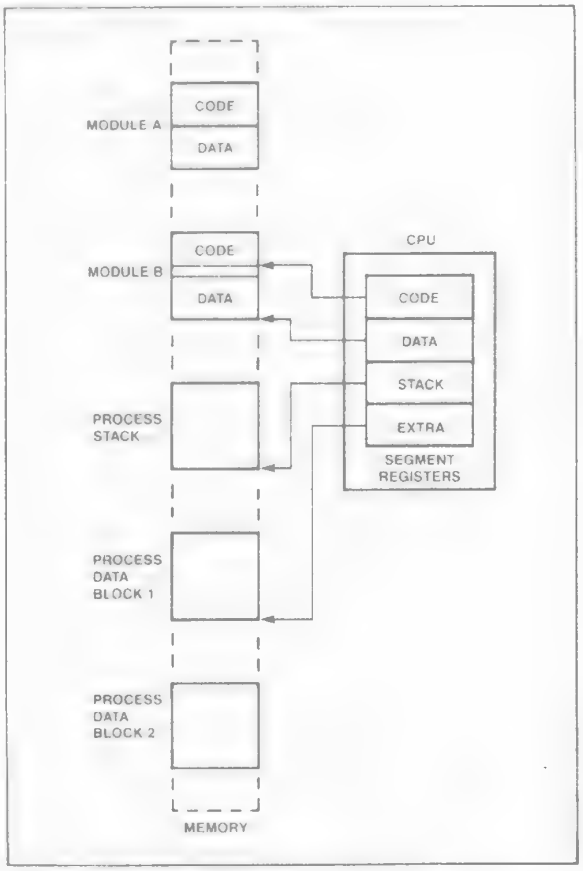

Figure 6. Segmented Memory Helps Structure Software

Addressing Modes

The 80186 provides eight categories of addressing modes to specify operands. Two addressing modes are provided for instructions that operate on register or immediate operands:

- *Register Operand Mode:* The operand is located in one of the 8- or 16-bit general registers.
- *Immediate Operand Mode:* The operand is included in the instruction.

Six modes are provided to specify the location of an operand in a memory segment. A memory operand address consists of two 16-bit components: a segment base and an offset. The segment base is supplied by a 16-bit segment register either implicity chosen by the addressing mode or explicitly chosen by a segment override prefix. The offset, also called the effective address, is calculated by summing any combination of the following three address elements:

- the *displacement* (an 8- or 16-bit immediate value contained in the instruction);
- the *base* (contents of either the BX or BP base registers); and
- the *index* (contents of either the SI or DI index registers).

Any carry out from the 16-bit addition is ignored. Eight-bit displacements are sign extended to 16-bit values.

Combinations of these three address elements define the six memory addressing modes, described below.

- *Direct Mode:* The operand's offset is contained in the instruction as an 8- or 16-bit displacement element.
- *Register Indirect Mode:* The operand's offset is in one of the registers SI, DI, BX, or BP.
- *Based Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of a base register (BX or BP).
- *Indexed Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of an index register (SI or DI).
- *Based Indexed Mode:* The operand's offset is the sum of the contents of a base register and an index register.
- *Based Indexed Mode with Displacement:* The operand's offset is the sum of a base register's contents, an index register's contents, and an 8- or 16-bit displacement.

Data Types

The 80186 directly supports the following data types:

- *Integer:* A signed binary numeric value contained in an 8-bit byte or a 16-bit word. All operations assume a 2's complement representation. Signed 32- and 64-bit integers are supported using the iAPX 186/20 Numeric Data Processor.
- *Ordinal:* An unsigned binary numeric value contained in an 8-bit byte or a 16-bit word.
- *Pointer:* A 16- or 32-bit quantity, composed of a 16-bit offset component or a 16-bit segment base component in addition to a 16-bit offset component.
- *String:* A contiguous sequence of bytes or words. A string may contain from 1 to 64K bytes.
- *ASCII:* A byte representation of alphanumeric and control characters using the ASCII standard of character representation.
- *BCD:* A byte (unpacked) representation of the decimal digits 0–9.
- *Packed BCD:* A byte (packed) representation of two decimal digits (0–9). One digit is stored in each nibble (4-bits) of the byte.
- *Floating Point:* A signed 32-, 64-, or 80-bit real number representation. (Floating point operands are supported using the iAPX 186/20 Numeric Data Processor configuration.)

In general, individual data elements must fit within defined segment limits. Figure 7 graphically represents the data types supported by the iAPX 186.

I/O Space

The I/O space consists of 64K 8-bit or 32K 16-bit ports. Separate instructions address the I/O space with either an 8-bit port address, specified in the instruction, or a 16-bit port address in the DX register. 8-bit port addresses are zero extended such that A_{15}-A_8 are LOW. I/O port addresses 00F8(H) through 00FF(H) are reserved.

Interrupts

An interrupt transfers execution to a new program location. The old program address (CS:IP) and machine state (Status Word) are saved on the stack to allow resumption of the interrupted program. Interrupts fall into three classes: hardware initiated, INT instructions, and instruction exceptions. Hardware initiated interrupts occur in response to an external input and are classified as non-maskable or maskable.

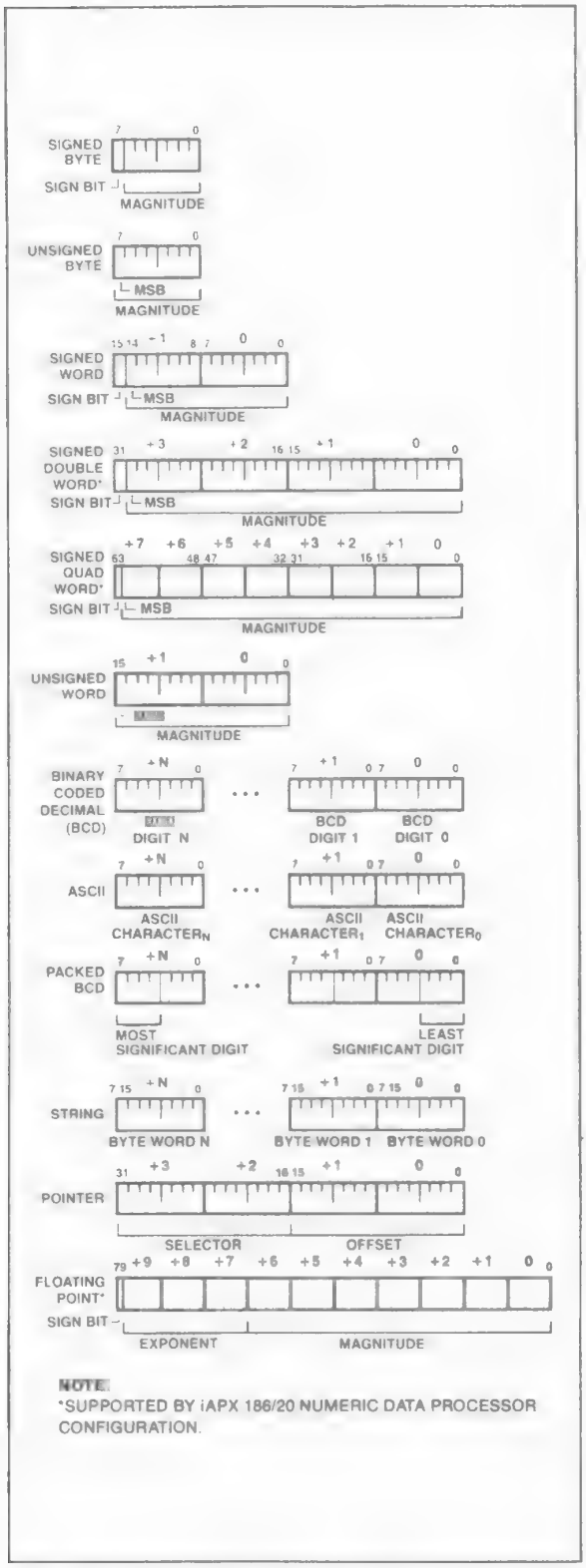

Figure 7. iAPX 186 Supported Data Types

Programs may cause an interrupt with an INT instruction. Instruction exceptions occur when an unusual condition, which prevents further instruction processing, is detected while attempting to execute an instruction. If the exception was caused by executing an ESC instruction with the ESC trap bit set in the relocation register, the return instruction will point to the ESC instruction, or to the segment override prefix immediately preceding the ESC instruction if the prefix was present. In all other cases, the return address from an exception will point at the instruction immediately following the instruction causing the exception.

A table containing up to 256 pointers defines the proper interrupt service routine for each interrupt. Interrupts 0–31, some of which are used for instruction exceptions, are reserved. Table 4 shows the 80186 predefined types and default priority levels. For each interrupt, an 8-bit vector must be supplied to the 80186 which identifies the appropriate table entry. Exceptions supply the interrupt vector internally. In addition, internal peripherals and non-cascaded external interrupts will generate their own vectors through the internal interrupt controller. INT instructions contain or imply the vector and allow access to all 256 interrupts. Maskable hardware initiated interrupts supply the 8-bit vector to the CPU during an interrupt acknowledge bus sequence. Non-maskable hardware interrupts use a predefined internally supplied vector.

Interrupt Sources

The 80186 can service interrupts generated by software or hardware. The software interrupts are generated by specific instructions (INT, ESC, unused OP, etc.) or the results of conditions specified by instructions (array bounds check, INT0, DIV, IDIV, etc.). All interrupt sources are serviced by an indirect call through an element of a vector table. This vector table is indexed by using the interrupt vector type (Table 4), multiplied by four. All hardware-generated interrupts are sampled at the end of each instruction. Thus, the software interrupts will begin service first. Once the service routine is entered and interrupts are enabled, any hardware source of sufficient priority can interrupt the service routine in progress.

The software generated 80186 interrupts are described below.

DIVIDE ERROR EXCEPTION (TYPE 0)

Generated when a DIV or IDIV instruction quotient cannot be expressed in the number of bits in the destination.

Table 4. 80186 Interrupt Vectors

Interrupt Name	Vector Type	Default Priority	Related Instructions
Divide Error Exception	0	*1	DIV, IDIV
Single Step Interrupt	1	12**2	All
NMI	2	1	All
Breakpoint Interrupt	3	*1	INT
INT0 Detected Overflow Exception	4	*1	INT0
Array Bounds Exception	5	*1	BOUND
Unused-Opcode Exception	6	*1	Undefined Opcodes
ESC Opcode Exception	7	*1***	ESC Opcodes
Timer 0 Interrupt	[illegible]	2A****	
Timer 1 Interrupt	18	2B****	
Timer 2 Interrupt	19	2C****	
Reserved	9	3	
DMA 0 Interrupt	10	4	
DMA 1 Interrupt	11	5	
INT0 Interrupt	12	6	
INT1 Interrupt	13	7	
INT2 Interrupt	14	[illegible]	
INT3 Interrupt	15	9	

NOTES:
*1. These are generated as the result of an instruction execution.
**2. This is handled as in the 8086.
****3. All three timers constitute one source of request to the interrupt controller. The Timer interrupts all have the same default priority level with respect to all other interrupt sources. However, they have a defined priority ordering amongst themselves. (Priority 2A is higher priority than 2B.) Each Timer interrupt has a separate vector type number.
4. Default priorities for the interrupt sources are used only if the user does not program each source into a unique priority level.
***5. An escape opcode will cause a trap only if the proper bit is set in the peripheral control block relocation register.

SINGLE-STEP INTERRUPT (TYPE 1)
Generated after most instructions if the TF flag is set. Interrupts will not be generated after prefix instructions (e.g., REP), instructions which modify segment registers (e.g., POP DS), or the WAIT instruction.

NON-MASKABLE INTERRUPT—NMI (TYPE 2)
An external interrupt source which cannot be masked.

BREAKPOINT INTERRUPT (TYPE 3)
A one-byte version of the INT instruction. It uses 12 as an index into the service routine address table (because it is a type 3 interrupt).

INT0 DETECTED OVERFLOW EXCEPTION (TYPE 4)
Generated during an INT0 instruction if the OF bit is set.

ARRAY BOUNDS EXCEPTION (TYPE 5)
Generated during a BOUND instruction if the array index is outside the array bounds. The array bounds are located in memory at a location indicated by one of the instruction operands. The other operand indicates the value of the index to be checked.

UNUSED OPCODE EXCEPTION (TYPE 6)
Generated if execution is attempted on undefined opcodes.

ESCAPE OPCODE EXCEPTION (TYPE 7)
Generated if execution is attempted of ESC opcodes (D8H–DFH). This exception will only be generated if a bit in the relocation register is set. The return address of this exception will point to the ESC instruction causing the exception. If a segment override prefix preceded the ESC instruction, the return address will point to the segment override prefix.

Hardware-generated interrupts are divided into two groups: maskable interrupts and non-maskable interrupts. The 80186 provides maskable hardware interrupt request pins INT0–INT3. In addition, maskable interrupts may be generated by the 80186 integrated DMA controller and the integrated timer unit. The vector types for these interrupts is shown in Table 4. Software enables these inputs by setting the interrupt flag bit (IF) in the Status Word. The interrupt controller is discussed in the peripheral section of this data sheet.

Further maskable interrupts are disabled while servicing an interrupt because the IF bit is reset as part of the response to an interrupt or exception. The saved Status Word will reflect the enable status of the processor prior to the interrupt. The interrupt flag will remain zero unless specifically set. The interrupt return instruction restores the Status Word, thereby restoring the original status of IF bit. If the interrupt return re-enables interrupts, and another interrupt is pending, the 80186 will immediately service the highest-priority interrupt pending, i.e., no instructions of the main line program will be executed.

Non-Maskable Interrupt Request (NMI)

A non-maskable interrupt (NMI) is also provided. This interrupt is serviced regardless of the state of the IF bit. A typical use of NMI would be to activate a power failure routine. The activation of this input

causes an interrupt with an internally supplied vector value of 2. No external interrupt acknowledge sequence is performed. The IF bit is cleared at the beginning of an NMI interrupt to prevent maskable interrupts from being serviced.

Single-Step Interrupt

The 80186 has an internal interrupt that allows programs to execute one instruction at a time. It is called the single-step interrupt and is controlled by the single-step flag bit (TF) in the Status Word. Once this bit is set, an internal single-step interrupt will occur after the next instruction has been executed. The interrupt clears the TF bit and uses an internally supplied vector of 1. The IRET instruction is used to set the TF bit and transfer control to the next instruction to be single-stepped.

Initialization and Processor Reset

Processor initialization or startup is accomplished by driving the $\overline{RES}$ input pin LOW. $\overline{RES}$ forces the 80186 to terminate all execution and local bus activity. No instruction or bus activity will occur as long as $\overline{RES}$ is active. After $\overline{RES}$ becomes inactive and an internal processing interval elapses, the 80186 begins execution with the instruction at physical location FFFF0(H). $\overline{RES}$ also sets some registers to predefined values as shown in Table 5.

Table 5. 80186 Initial Register State after RESET

Status Word	F002(H)
Instruction Pointer	0000(H)
Code Segment	FFFF(H)
Data Segment	0000(H)
Extra Segment	0000(H)
Stack Segment	0000(H)
Relocation Register	20FF(H)
UMCS	FFFB(H)

iAPX 186 CLOCK GENERATOR

The iAPX 186 provides an on-chip clock generator for both internal and external clock generation. The clock generator features a crystal oscillator, a divide-by-two counter, synchronous and asynchronous ready inputs, and reset circuitry.

Oscillator

The oscillator circuit of the iAPX 186 is designed to be used with a parallel resonant fundamental mode crystal. This is used as the time base for the iAPX 186. The crystal frequency selected will be double the CPU clock frequency. Use of an LC or RC circuit is not recommended with this oscillator. If an external oscillator is used, it can be connected directly to input pin X1 in lieu of a crystal. The output of the oscillator is not directly available outside the iAPX 186. The recommended crystal configuration is shown in Figure 8.

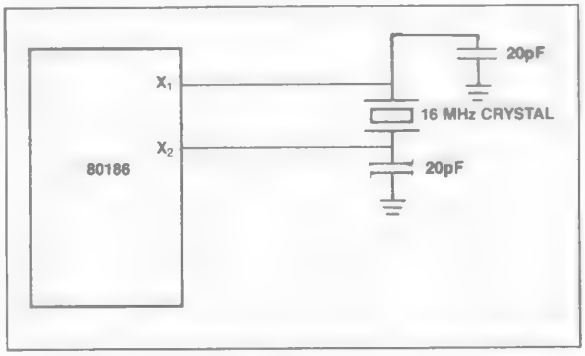

Figure 8. Recommended iAPX 186 Crystal Configuration

Clock Generator

The iAPX 186 clock generator provides the 50% duty cycle processor clock for the iAPX 186. It does this by dividing the oscillator output by 2 forming the symmetrical clock. If an external oscillator is used, the state of the clock generator will change on the falling edge of the oscillator signal. The CLKOUT pin provides the processor clock signal for use outside the iAPX 186. This may be used to drive other system components. All timings are referenced to the output clock.

READY Synchronization

The iAPX 186 provides both synchronous and asynchronous ready inputs. Asynchronous ready synchronization is accomplished by circuitry which samples ARDY in the middle of T_2, T_3 and again in the middle of each T_W until ARDY is sampled HIGH. One-half CLKOUT cycle of resolution time is used. Full synchronization is performed only on the rising edge of ARDY, i.e., the falling edge of ARDY must be synchronized to the CLKOUT signal if it will occur during T_2, T_3 or T_W. High-to-LOW transitions of ARDY must be performed synchronously to the CPU clock.

A second ready input (SRDY) is provided to interface with externally synchronized ready signals. This input is sampled at the end of T_2, T_3 and again at the end of each T_W until it is sampled HIGH. By using this input rather than the asynchronous ready input, the half-clock cycle resolution time penalty is eliminated.

This input must satisfy set-up and hold times to guarantee proper operation of the circuit.

In addition, the iAPX 186, as part of the integrated chip-select logic, has the capability to program WAIT states for memory and peripheral blocks. This is discussed in the Chip Select/Ready Logic description.

RESET Logic

The iAPX 186 provides both a $\overline{RES}$ input pin and a synchronized RESET pin for use with other system components. The $\overline{RES}$ input pin on the iAPX 186 is provided with hysteresis in order to facilitate power-on Reset generation via an RC network. RESET is guaranteed to remain active for at least five clocks given a $\overline{RES}$ input of at least six clocks. RESET may be delayed up to two and one-half clocks behind $\overline{RES}$.

Multiple iAPX 186 processors may be synchronized through the $\overline{RES}$ input pin, since this input resets both the processor and divide-by-two internal counter in the clock generator. In order to insure that the divide-by-two counters all begin counting at the same time, the active going edge of $\overline{RES}$ must satisfy a 25 ns setup time before the falling edge of the 80186 clock input. In addition, in order to insure that all CPUs begin executing in the same clock cycle, the reset must satisfy a 25 ns setup time before the rising edge of the CLKOUT signal of all the processors.

LOCAL BUS CONTROLLER

The iAPX 186 provides a local bus controller to generate the local bus control signals. In addition, it employs a HOLD/HLDA protocol for relinquishing the local bus to other bus masters. It also provides control lines that can be used to enable external buffers and to direct the flow of data on and off the local bus.

Memory/Peripheral Control

The iAPX 186 provides ALE, $\overline{RD}$, and $\overline{WR}$ bus control signals. The $\overline{RD}$ and $\overline{WR}$ signals are used to strobe data from memory to the iAPX 186 or to strobe data from the iAPX 186 to memory. The ALE line provides a strobe to address latches for the multiplexed address/data bus. The iAPX 186 local bus controller does not provide a memory/$\overline{I/O}$ signal. If this is required, the user will have to use the $\overline{S2}$ signal (which will require external latching), make the memory and I/O spaces nonoverlapping, or use only the integrated chip-select circuitry.

Transceiver Control

The iAPX 186 generates two control signals to be connected to 8286/8287 transceiver chips. This capability allows the addition of transceivers for extra buffering without adding external logic. These control lines, DT/$\overline{R}$ and $\overline{DEN}$, are generated to control the flow of data through the transceivers. The operation of these signals is shown in Table 6.

Table 6. Transceiver Control Signals Description

Pin Name	Function
$\overline{DEN}$ (Data Enable)	Enables the output drivers of the transceivers. It is active LOW during memory, I/O, or INTA cycles.
DT/$\overline{R}$ (Data Transmit/Receive)	Determines the direction of travel through the transceivers. A HIGH level directs data away from the processor during write operations, while a LOW level directs data toward the processor during a read operation.

Local Bus Arbitration

The iAPX 186 uses a HOLD/HLDA system of local bus exchange. This provides an asynchronous bus exchange mechanism. This means multiple masters utilizing the same bus can operate at separate clock frequencies. The iAPX 186 provides a single HOLD/HLDA pair through which all other bus masters may gain control of the local bus. This requires external circuitry to arbitrate which external device will gain control of the bus from the iAPX 186 when there is more than one alternate local bus master. When the iAPX 186 relinquishes control of the local bus, it floats $\overline{DEN}$, $\overline{RD}$, $\overline{WR}$, $\overline{S0}$–$\overline{S2}$, $\overline{LOCK}$, AD0–AD15, A16–A19, $\overline{BHE}$, and DT/$\overline{R}$ to allow another master to drive these lines directly.

The iAPX 186 HOLD latency time, i.e., the time between HOLD request and HOLD acknowledge, is a function of the activity occurring in the processor when the HOLD request is received. A HOLD request is the highest-priority activity request which the processor may receive: higher than instruction fetching or internal DMA cycles. However, if a DMA cycle is in progress, the iAPX 186 will complete the transfer before relinquishing the bus. This implies that if a HOLD request is received just as a DMA transfer begins, the HOLD latency time can be as great as 4 bus cycles. This will occur if a DMA word transfer operation is taking place from an odd address to an odd address. This is a total of 16 clocks or more, if WAIT states are required. In addition, if locked transfers are performed, the HOLD latency time will be increased by the length of the locked transfer.

Local Bus Controller and Reset

Upon receipt of a RESET pulse from the $\overline{RES}$ input, the local bus controller will perform the following actions:

- Drive $\overline{DEN}$, $\overline{RD}$, and $\overline{WR}$ HIGH for one clock cycle, then float.

  NOTE: $\overline{RD}$ is also provided with an internal pull-up device to prevent the processor from inadvertently entering Queue Status mode during reset.

- Drive $\overline{S0}$–$\overline{S2}$ to the passive state (all HIGH) and then float.
- Drive $\overline{LOCK}$ HIGH and then float.
- Tristate AD0–15, A16–19, $\overline{BHE}$, DT/$\overline{R}$.
- Drive ALE LOW (ALE is never floated).
- Drive HLDA LOW.

INTERNAL PERIPHERAL INTERFACE

All the iAPX 186 integrated peripherals are controlled via 16-bit registers contained within an internal 256-byte control block. This control block may be mapped into either memory or I/O space. Internal logic will recognize the address and respond to the bus cycle. During bus cycles to internal registers, the bus controller will signal the operation externally (i.e., the $\overline{RD}$, $\overline{WR}$, status, address, data, etc., lines will be driven as in a normal bus cycle), but D_{15-0}, SRDY, and ARDY will be ignored. The base address of the control block must be on an even 256-byte boundary (i.e., the lower 8 bits of the base address are all zeros). All of the defined registers within this control block may be read or written by the 80186 CPU at any time. The location of any register contained within the 256-byte control block is determined by the current base address of the control block.

The control block base address is programmed via a 16-bit relocation register contained within the control block at offset FEH from the base address of the control block (see Figure 9). It provides the upper 12 bits of the base address of the control block. Note that mapping the control register block into an address range corresponding to a chip-select range is not recommended (the chip select circuitry is discussed later in this data sheet). In addition, bit 12 of this register determines whether the control block will be mapped into I/O or memory space. If this bit is 1, the control block will be located in memory space, whereas if the bit is 0, the control block will be located in I/O space. If the control register block is mapped into I/O space, the upper 4 bits of the base address must be programmed as 0 (since I/O addresses are only 16 bits wide).

In addition to providing relocation information for the control block, the relocation register contains bits which place the interrupt controller into iRMX mode, and cause the CPU to interrupt upon encountering ESC instructions. At RESET, the relocation register is set to 20FFH. This causes the control block to start at FF00H in I/O space. An offset map of the 256-byte control register block is shown in Figure 10.

The integrated iAPX 186 peripherals operate semi-autonomously from the CPU. Access to them for the most part is via software read/write of the control and data locations in the control block. Most of these registers can be both read and written. A few dedicated lines, such as interrupts and DMA request provide real-time communication between the CPU and peripherals as in a more conventional system utilizing discrete peripheral blocks. The overall interaction and function of the peripheral blocks has not substantially changed.

CHIP-SELECT/READY GENERATION LOGIC

The iAPX 186 contains logic which provides programmable chip-select generation for both memories and peripherals. In addition, it can be programmed to provide READY (or WAIT state) generation. It can also provide latched address bits A1 and A2. The chip-select lines are active for all memory and I/O cycles in their programmed areas, whether they be generated by the CPU or by the integrated DMA unit.

Memory Chip Selects

The iAPX 186 provides 6 memory chip select outputs for 3 address areas: upper memory, lower memory, and midrange memory. One each is provided for upper memory and lower memory, while four are provided for midrange memory.

The range for each chip select is user-programmable and can be set to 2K, 4K, 8K, 16K, 32K, 64K, 128K (plus 1K and 256K for upper and lower chip selects). In addition, the beginning or base address of the midrange memory chip select may also be selected. Only one chip select may be programmed to be active for any memory location at a time. All chip select sizes are in bytes, whereas iAPX 186 memory is arranged in words. This means that if, for example, 16 64K x 1 memories are used, the memory block size will be 128K, not 64K.

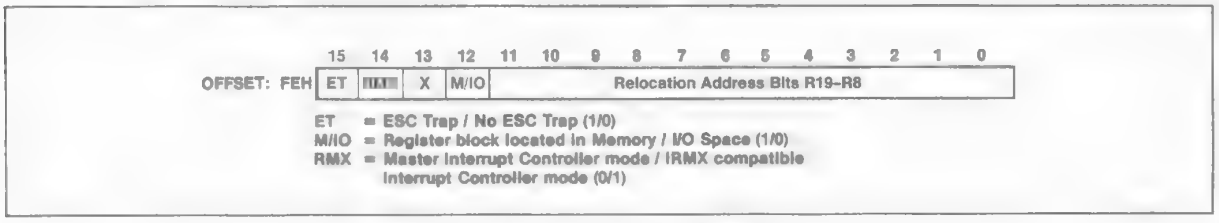

Figure 9. Relocation Register

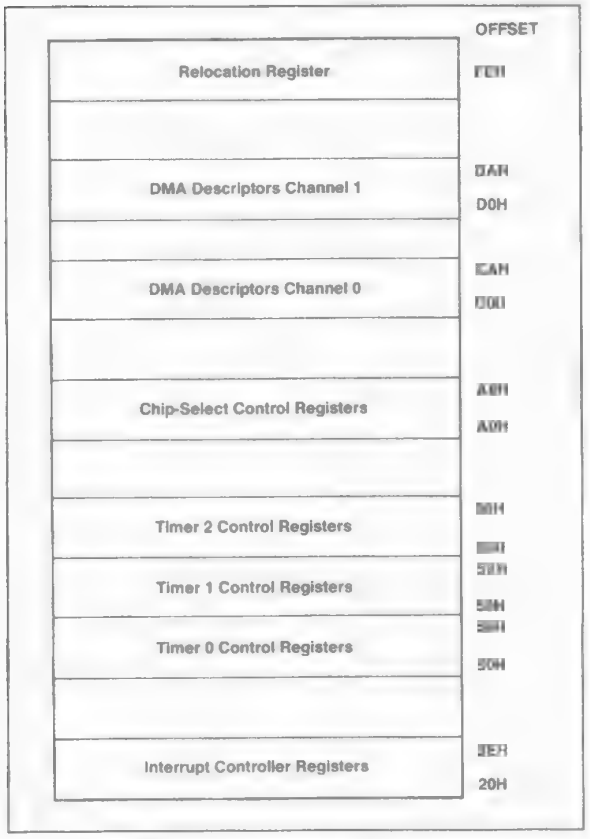

Figure 10. Internal Register Map

Upper Memory $\overline{CS}$

The iAPX 186 provides a chip select, called $\overline{UCS}$, for the top of memory. The top of memory is usually used as the system memory because after reset the iAPX 186 begins executing at memory location FFFF0H.

The upper limit of memory defined by this chip select is always FFFFFH, while the lower limit is programmable. By programming the lower limit, the size of the select block is also defined. Table 7 shows the relationship between the base address selected and the size of the memory block obtained.

Table 7. UMCS Programming Values

Starting Address (Base Address)	Memory Block Size	UMCS Value (Assuming R0=R1=R2=0)
FFC00	1K	FFF8H
FF800	2K	FFB8H
FF000	4K	FF38H
FE000	8K	FE38H
FC000	16K	FC38H
F8000	32K	F838H
F0000	64K	F038H
E0000	128K	E038H
C0000	256K	C038H

The lower limit of this memory block is defined in the UMCS register (see Figure 11). This register is at offset A0H in the internal control block. The legal values for bits 6–13 and the resulting starting address and memory block sizes are given in Table 7. Any combination of bits 6–13 not shown in Table 7 will result in undefined operation. After reset, the UMCS register is programmed for a 1K area. It must be reprogrammed if a larger upper memory area is desired.

Any internally generated 20-bit address whose upper 16 bits are greater than or equal to UMCS (with bits 0–5 "0") will cause UCS to be activated. UMCS bits R2–R0 are used to specify READY mode for the area of memory defined by this chip-select register, as explained below.

Lower Memory $\overline{CS}$

The iAPX 186 provides a chip select for low memory called $\overline{LCS}$. The bottom of memory contains the interrupt vector table, starting at location 00000H.

The lower limit of memory defined by this chip select is always 0H, while the upper limit is programmable. By programming the upper limit, the size of the memory block is also defined. Table 8 shows the relationship between the upper address selected and the size of the memory block obtained.

Table 8. LMCS Programming Values

Upper Address	Memory Block Size	LMCS Value (Assuming R0=R1=R2=0)
003FFH	1K	0038H
007FFH	2K	0078H
00FFFH	4K	00F8H
01FFFH	8K	01F8H
03FFFH	16K	03F8H
07FFFH	32K	07F8H
0FFFFH	64K	0FF8H
1FFFFH	128K	1FF8H
3FFFFH	256K	3FF8H

The upper limit of this memory block is defined in the LMCS register (see Figure 12). This register is at offset A2H in the internal control block. The legal values for bits 6–15 and the resulting upper address and memory block sizes are given in Table 8. Any combination of bits 6–15 not shown in Table 8 will result in undefined operation. After reset, the LMCS register value is undefined. However, the $\overline{LCS}$ chip-select line will not become active until the LMCS register is accessed.

Any internally generated 20-bit address whose upper 16 bits are less than or equal to LMCS (with bits 0–5 "1") will cause $\overline{LCS}$ to be active. LMCS register bits R2–R0 are used to specify the READY mode for the area of memory defined by this chip-select register.

Mid-Range Memory $\overline{CS}$

The iAPX 186 provides four $\overline{MCS}$ lines which are active within a user-locatable memory block. This block can be located anywhere within the iAPX 186 1M byte memory address space exclusive of the areas defined by $\overline{UCS}$ and $\overline{LCS}$. Both the base address and size of this memory block are programmable.

The size of the memory block defined by the mid-range select lines, as shown in Table 9, is determined by bits 8–14 of the MPCS register (see Figure 13). This register is at location A8H in the internal control block. One and only one of bits 8–14 must be set at a time. Unpredictable operation of the $\overline{MCS}$ lines will otherwise occur. Each of the four chip-select lines is active for one of the four equal contiguous divisions of the mid-range block. Thus, if the total block size is 32K, each chip select is active for 8K of memory with $\overline{MCS0}$ being active for the first range and $\overline{MCS3}$ being active for the last range.

The EX and MS in MPCS relate to peripheral functionality as descibed a later section.

Table 9. MPCS Programming Values

Total Block Size	Individual Select Size	MPCS Bits 14–8
8K	2K	0000001B
16K	4K	0000010B
32K	8K	0000100B
64K	16K	0001000B
128K	32K	0010000B
256K	64K	0100000B
512K	128K	1000000B

The base address of the mid-range memory block is defined by bits 15–9 of the MMCS register (see Figure 14). This register is at offset A6H in the internal control block. These bits correspond to bits A19–A13 of the 20-bit memory address. Bits A12–A0 of the base address are always 0. The base address may be set at any integer multiple of the size of the total memory block selected. For example, if the mid-range block size is 32K (or the size of the block for which each $\overline{MCS}$ line is active is 8K), the block could be located at 10000H or 18000H, but not at 14000H, since the first few integer multiples of a 32K memory block are 0H, 8000H, 10000H, 18000H, etc. After reset, the contents of both of these registers is undefined. However, none of the $\overline{MCS}$ lines will be active until both the MMCS and MPCS registers are accessed.

Figure 11. UMCS Register

Figure 12. LMCS Register

OFFSET:	A8H	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
		1	M6	M5	M4	M3	M2	M1	M0	EX	MS	1	1	1	R2	R1	R0

Figure 13. MPCS Register

OFFSET:	A6H	15						▮						▮			0
		U	U	U	U	U	U	U	1	1	1	1	1	1	R2	R1	R0
		A19						A13									

Figure 14. MMCS Register

MMCS bits R2–R0 specify READY mode of operation for all mid-range chip selects. All devices in mid-range memory must use the same number of WAIT states.

The 512K block size for the mid-range memory chip selects is a special case. When using 512K, the base address would have to be at either locations 00000H or 80000H. If it were to be programmed at 00000H when the $\overline{LCS}$ line was programmed, there would be an internal conflict between the $\overline{LCS}$ ready generation logic and the $\overline{MCS}$ ready generation logic. Likewise, if the base address were programmed at 80000H, there would be a conflict with the $\overline{UCS}$ ready generation logic. Since the $\overline{LCS}$ chip-select line does not become active until programmed, while the $\overline{UCS}$ line is active at reset, the memory base can be set only at 00000H. If this base address is selected, however, the $\overline{LCS}$ range must not be programmed.

Peripheral Chip Selects

The iAPX 186 can generate chip selects for up to seven peripheral devices. These chip selects are active for seven contiguous blocks of 128 bytes above a programmable base address. This base address may be located in either memory or I/O space.

Seven $\overline{CS}$ lines called $\overline{PCS0}$–6 are generated by the iAPX 186. The base address is user-programmable; however it can only be a multiple of 1K bytes, i.e., the least significant 10 bits of the starting address are always 0.

$\overline{PCS5}$ and $\overline{PCS6}$ can also be programmed to provide latched address bits A1, A2. If so programmed, they cannot be used as peripheral selects. These outputs can be connected directly to the A0, A1 pins used for selecting internal registers of 8-bit peripheral chips. This scheme simplifies the hardware interface because the 8-bit registers of peripherals are simply treated as 16-bit registers located on even boundaries in I/O space or memory space where only the lower 8-bits of the register are significant: the upper 8-bits are "don't cares."

The starting address of the peripheral chip-select block is defined by the PACS register (see Figure 15). This register is located at offset A4H in the internal control block. Bits 15–6 of this register correspond to bits 19–10 of the 20-bit Programmable Base Address (PBA) of the peripheral chip-select block. Bits 9–0 of the PBA of the peripheral chip-select block are all zeros. If the chip-select block is located in I/O space, bits 12–15 must be programmed zero, since the I/O address is only 16 bits wide. Table 10 shows the address range of each peripheral chip select with respect to the PBA contained in PACS register.

OFFSET:	A4H	15									6	5		▮			0
		U	U	U	U	U	U	U	U	U	U	1	1	1	R2	R1	R0
		A19									A10						

Figure 15. PACS Register

The user should program bits 15–6 to correspond to the desired peripheral base location. PACS bits 0–2 are used to specify READY mode for $\overline{PCS0}$–$\overline{PCS3}$.

Table 10. PCS Address Ranges

PCS Line	Active between Locations
PCS0	PBA —PBA+127
PCS1	PBA+128 —PBA+255
PCS2	PBA+256 —PBA+383
PCS3	PBA+384 —PBA+511
PCS4	PBA+512 —PBA+639
PCS5	PBA+640 —PBA+767
PCS6	PBA+768 —PBA+895

The mode of operation of the peripheral chip selects is defined by the MPCS register (which is also used to set the size of the mid-range memory chip-select block, see Figure 16). This register is located at offset A8H in the internal control block. Bit 7 is used to select the function of $\overline{PCS5}$ and $\overline{PCS6}$, while bit 6 is used to select whether the peripheral chip selects are mapped into memory or I/O space. Table 11 describes the programming of these bits. After reset, the contents of both the MPCS and the PACS registers are undefined, however none of the PCS lines will be active until both of the MPCS and PACS registers are accessed.

Table 11. MS, EX Programming Values

Bit	Description
MS	1 = Peripherals mapped into memory space. 0 = Peripherals mapped into I/O space.
EX	0 = 5 $\overline{PCS}$ lines. A1, A2 provided. 1 = 7 $\overline{PCS}$ lines. A1, A2 are not provided.

MPCS bits 0–2 are used to specify READY mode for $\overline{PCS4}$–$\overline{PCS6}$ as outlined below.

READY Generation Logic

The iAPX 186 can generate a "READY" signal internally for each of the memory or peripheral $\overline{CS}$ lines. The number of WAIT states to be inserted for each peripheral or memory is programmable to provide 0–3 wait states for all accesses to the area for which the chip select is active. In addition, the iAPX 186 may be programmed to either ignore external READY for each chip-select range individually or to factor external READY with the integrated ready generator.

READY control consists of 3 bits for each $\overline{CS}$ line or group of lines generated by the iAPX 186. The interpretation of the ready bits is shown in Table 12.

Table 12. READY Bits Programming

R2	R1	R0	Number of WAIT States Generated
0	0	0	0 wait states, external RDY also used.
0	0	1	1 wait state inserted, external RDY also used.
0	1	0	2 wait states inserted, external RDY also used.
0	1	1	3 wait states inserted, external RDY also used.
1	0	0	0 wait states, external RDY ignored.
1	0	1	1 wait state inserted, external RDY ignored.
1	1	0	2 wait states inserted, external RDY ignored.
1	1	1	3 wait states inserted, external RDY ignored.

The internal ready generator operates in parallel with external READY, not in series if the external READY is used (R2 = 0). This means, for example, if the internal generator is set to insert two wait states, but activity on the external READY lines will insert four wait states, the processor will only insert four wait states, not six. This is because the two wait states generated by the internal generator overlapped the first two wait states generated by the external ready signal. Note that the external ARDY and SRDY lines are always ignored during cycles accessing internal peripherals.

R2–R0 of each control word specifies the READY mode for the corresponding block, with the exception of the peripheral chip selects: R2–R0 of PACS set the $\overline{PCS0}$–3 READY mode, R2–R0 of MPCS set the $\overline{PCS4}$–6 READY mode.

Chip Select/Ready Logic and Reset

Upon reset, the Chip-Select/Ready Logic will perform the following actions:

- All chip-select outputs will be driven HIGH.
- Upon leaving RESET, the $\overline{UCS}$ line will be programmed to provide chip selects to a 1K block with the accompanying READY control bits set at 011 to

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OFFSET: A8H	1	M6	M5	M4	M3	M2	M1	M0	EX	MS	1	1	1	R2	R1	R0

Figure 16. MPCS Register

allow the maximum number of internal wait states in conjunction with external Ready consideration (i.e., UMCS resets to FFFBH).

- No other chip select or READY control registers have any predefined values after RESET. They will not become active until the CPU accesses their control registers. Both the PACS and MPCS registers must be accessed before the $\overline{PCS}$ lines will become active.

DMA CHANNELS

The 80186 DMA controller provides two independent high-speed DMA channels. Data transfers can occur between memory and I/O spaces (e.g., Memory to I/O) or within the same space (e.g., Memory to Memory or I/O to I/O). Data can be transferred either in bytes (8 bits) or in words (16 bits) to or from even or odd addresses. Each DMA channel maintains both a 20-bit source and destination pointer which can be optionally incremented or decremented after each data transfer (by one or two depending on byte or word transfers). Each data transfer consumes 2 bus cycles (a minimum of 8 clocks), one cycle to fetch data and the other to store data. This provides a maximum data transfer rate of one Mword/sec or 2 MBytes/sec.

DMA Operation

Each channel has six registers in the control block which define each channel's specific operation. The control registers consist of a 20-bit Source pointer (2 words), a 20-bit Destination pointer (2 words), a 16-bit Transfer Counter, and a 16-bit Control Word. The format of the DMA Control Blocks is shown in Table 13. The Transfer Count Register (TC) specifies the number of DMA transfers to be performed. Up to 64K byte or word transfers can be performed with automatic termination. The Control Word defines the channel's operation (see Figure 18). All registers may be modified or altered during any DMA activity. Any changes made to these registers will be reflected immediately in DMA operation.

Table 13. DMA Control Block Format

Register Name	Register Address	
	Ch. 0	Ch. 1
Control Word	CAH	DAH
Transfer Count	C8H	D8H
Destination Pointer (upper 4 bits)	C6H	D6H
Destination Pointer	C4H	D4H
Source Pointer (upper 4 bits)	C2H	D2H
Source Pointer	C0H	D0H

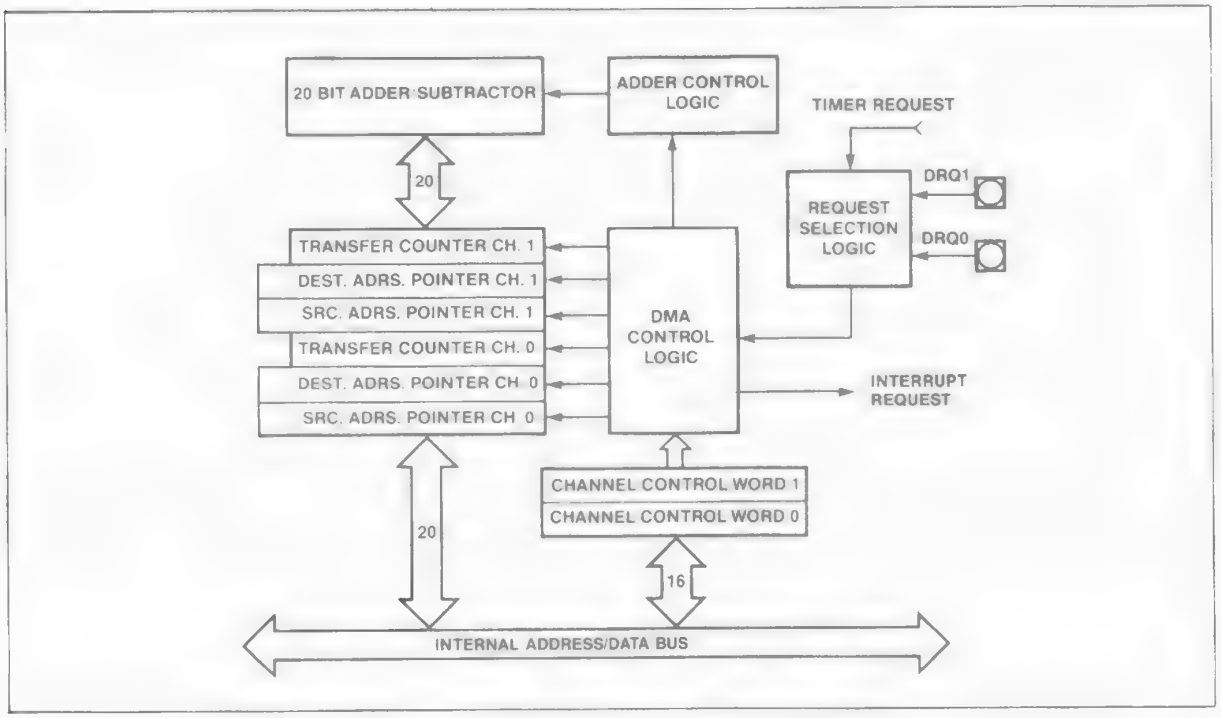

Figure 17. DMA Unit Block Diagram

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
M/IO	DESTINATION DEC	INC	M/IO	SOURCE DEC	INC	TC	INT	SYN		P	TDRQ	X	CHG/NOCHG	ST/STOP	B/W

X – DON'T CARE.

Figure 18. DMA Control Register

DMA Channel Control Word Register

Each DMA Channel Control Word determines the mode of operation for the particular 80186 DMA channel. This register specifies:

- the mode of synchronization;
- whether bytes or words will be transferred;
- whether interrupts will be generated after the last transfer;
- whether DMA activity will cease after a programmed number of DMA cycles;
- the relative priority of the DMA channel with respect to the other DMA channel;
- whether the source pointer will be incremented, decremented, or maintained constant after each transfer;
- whether the source pointer addresses memory or I/O space;
- whether the destination pointer will be incremented, decremented, or maintained constant after each transfer; and
- whether the destination pointer will address memory or I/O space.

The DMA channel control registers may be changed while the channel is operating. However, any changes made during operation will affect the current DMA transfer.

DMA Control Word Bit Descriptions

B/W: Byte/Word (0/1) Transfers.

ST/STOP: Start/stop (1/0) Channel.

CHG/NOCHG: Change/Do not change (1/0) ST/STOP bit. If this bit is set when writing to the control word, the ST/STOP bit will be programmed by the write to the control word. If this bit is cleared when writing the control word, the ST/STOP bit will not be altered. This bit is not stored; it will always be a 0 on read.

INT: Enable Interrupts to CPU on Transfer Count termination.

TC: If set, DMA will terminate when the contents of the Transfer Count register reach zero. The ST/STOP bit will also be reset at this point if TC is set. If this bit is cleared, the DMA unit will decrement the transfer count register for each DMA cycle, but the DMA transfer will not stop when the contents of the TC register reach zero.

SYN: (2 bits)
- 00 No synchronization.
  NOTE: The ST bit will be cleared automatically when the contents of the TC register reach zero regardless of the state of the TC bit.
- 01 Source synchronization.
- 10 Destination synchronization.
- 11 Unused.

SOURCE:INC Increment source pointer by 1 or 2 (depends on B/W) after each transfer.

M/IO Source pointer is in M/IO space (1/0).

DEC Decrement source pointer by 1 or 2 (depends on B/W) after each transfer.

DEST: INC Increment destination pointer by 1 or 2 (B/W) after each transfer.

M/IO Destination pointer is in M/IO space (1/0).

DEC Decrement destination pointer by 1 or 2 (depending on B/W) after each transfer.

P Channel priority—relative to other channel.
- 0 low priority.
- 1 high priority.

Channels will alternate cycles if both set at same priority level.

TDRQ	0: Disable DMA requests from timer 2.
	1: Enable DMA requests from timer 2.
Bit 3	Bit 3 is not used.

If both INC and DEC are specified for the same pointer, the pointer will remain constant after each cycle.

DMA Destination and Source Pointer Registers

Each DMA channel maintains a 20-bit source and a 20-bit destination pointer. Each of these pointers takes up two full 16-bit registers in the peripheral control block. The lower four bits of the upper register contain the upper four bits of the 20-bit physical address (see Figure 18a). These pointers may be individually incremented or decremented after each transfer. If word transfers are performed the pointer is incremented or decremented by two. Each pointer may point into either memory or I/O space. Since the DMA channels can perform transfers to or from odd addresses, there is no restriction on values for the pointer registers. Higher transfer rates can be obtained if all word transfers are performed to even addresses, since this will allow data to be accessed in a single memory access.

DMA Transfer Count Register

Each DMA channel maintains a 16-bit transfer count register (TC). This register is decremented after every DMA cycle, regardless of the state of the TC bit in the DMA Control Register. If the TC bit in the DMA control word is set or unsynchronized transfers are programmed, however, DMA activity will terminate when the transfer count register reaches zero.

DMA Requests

Data transfers may be either source or destination synchronized, that is either the source of the data or the destination of the data may request the data transfer. In addition, DMA transfers may be unsynchronized; that is, the transfer will take place continually until the correct number of transfers has occurred. When source or unsynchronized transfers are performed, the DMA channel may begin another transfer immediately after the end of a previous DMA transfer. This allows a complete transfer to take place every 2 bus cycles or eight clock cycles (assuming no wait states). No prefetching occurs when destination synchronization is performed, however. Data will not be fetched from the source address until the destination device signals that it is ready to receive it. When destination synchronized transfers are requested, the DMA controller will relinquish control of the bus after every transfer. If no other bus activity is initiated, another DMA cycle will begin after two processor clocks. This is done to allow the destination device time to remove its request if another transfer is not desired. Since the DMA controller will relinquish the bus, the CPU can initiate a bus cycle. As a result, a complete bus cycle will often be inserted between destination synchronized transfers. These lead to the maximum DMA transfer rates shown in Table 14.

Table 14. Maximum DMA Transfer Rates

Type of Synchronization Selected	CPU Running	CPU Halted
Unsynchronized	2MBytes/sec	2MBytes/sec
Source Synch	2MBytes/sec	2MBytes/sec
Destination Synch	1.3MBytes/sec	1.5MBytes/sec

HIGHER REGISTER ADDRESS	XXX	XXX	XXX	A19–A16
LOWER REGISTER ADDRESS	A15–A12	A11–A8	A7–A4	A3–A0

15 0

XXX = DON'T CARE

Figure 18a. DMA Memory Pointer Register Format

DMA Acknowledge

No explicit DMA acknowledge pulse is provided. Since both source and destination pointers are maintained, a read from a requesting source, or a write to a requesting destination, should be used as the DMA acknowledge signal. Since the chip-select lines can be programmed to be active for a given block of memory or I/O space, and the DMA pointers can be programmed to point to the same given block, a chip-select line could be used to indicate a DMA acknowledge.

DMA Priority

The DMA channels may be programmed such that one channel is always given priority over the other, or they may be programmed such as to alternate cycles when both have DMA requests pending. DMA cycles always have priority over internal CPU cycles except between locked memory accesses or word accesses the odd memory locations; however, an external bus hold takes priority over an internal DMA cycle. Because an interrupt request cannot suspend a DMA operation and the CPU cannot access memory during a DMA cycle, interrupt latency time will suffer during sequences of continuous DMA cycles. An NMI request, however, will cause all internal DMA activity to halt. This allows the CPU to quickly respond to the NMI request.

DMA Programming

DMA cycles will occur whenever the ST/STOP bit of the Control Register is set. If synchronized transfers are programmed, a DRQ must also have been generated. Therefore, the source and destination transfer pointers, and the transfer count register (if used) must be programmed before this bit is set.

Each DMA register may be modified while the channel is operating. If the CHG/NOCHG bit is cleared when the control register is written, the ST/STOP bit of the control register will not be modified by the write. If multiple channel registers are modified, it is recommended that a LOCKED string transfer be used to prevent a DMA transfer from occurring between updates to the channel registers.

DMA Channels and Reset

Upon RESET, the DMA channels will perform the following actions:

- The Start/Stop bit for each channel will be reset to STOP.
- Any transfer in progress is aborted.

TIMERS

The 80186 provides three internal 16-bit programmable timers (see Figure 19). Two of these are highly flexible and are connected to four external pins (2 per timer). They can be used to count external events, time external events, generate nonrepetitive waveforms, etc. The third timer is not connected to any external pins, and is useful for real-time coding and time delay applications. In addition, this third timer can be used as a prescaler to the other two, or as a DMA request source.

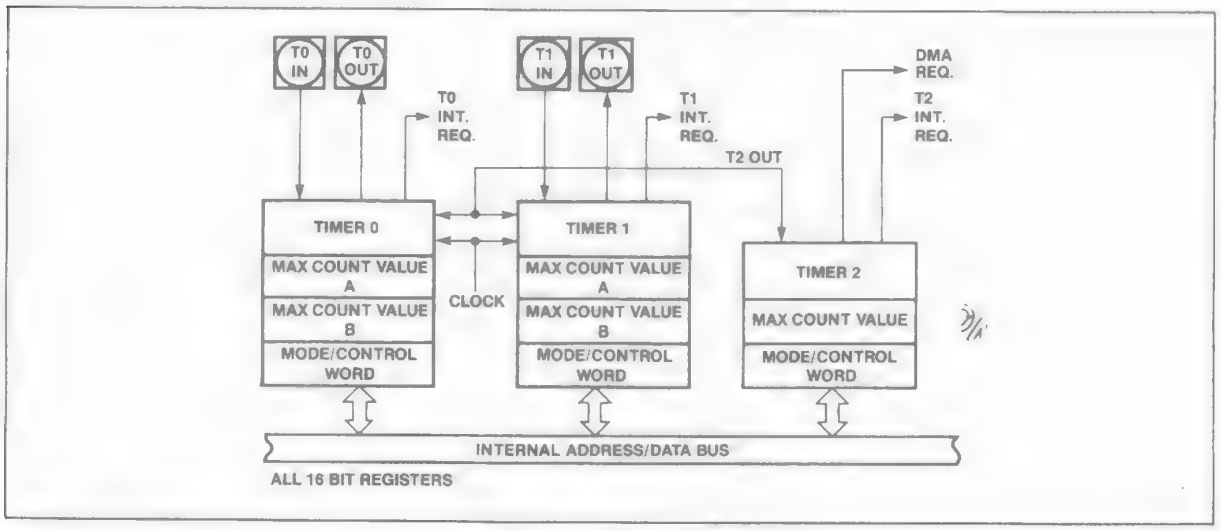

Figure 19. Timer Block Diagram

Timer Operation

The timers are controlled by 11 16-bit registers in the internal peripheral control block. The configuration of these registers is shown in Table 15. The count register contains the current value of the timer. It can be read or written at any time independent of whether the timer is running or not. The value of this register will be incremented for each timer event. Each of the timers is equipped with a MAX COUNT register, which defines the maximum count the timer will reach. After reaching the MAX COUNT register value, the timer count value will reset to zero during that same clock, i.e., the maximum count value is never stored in the count register itself. Timers 0 and 1 are, in addition, equipped with a second MAX COUNT register, which enables the timers to alternate their count between two different MAX COUNT values programmed by the user. If a single MAX COUNT register is used, the timer output pin will switch LOW for a single clock, 2 clocks after the maximum count value has been reached. In the dual MAX COUNT register mode, the output pin will indicate which MAX COUNT register is currently in use, thus allowing nearly complete freedom in selecting waveform duty cycles. For the timers with two MAX COUNT registers, the RIU bit in the control register determines which is used for the comparison.

Each timer gets serviced every fourth CPU-clock cycle, and thus can operate at speeds up to one-quarter the internal clock frequency (one-eighth the crystal rate). External clocking of the timers may be done at up to a rate of one-quarter of the internal CPU-clock rate (2 MHz for an 8 MHz CPU clock). Due to internal synchronization and pipelining of the timer circuitry, a timer output may take up to 6 clocks to respond to any individual clock or gate input. Since the count registers and the maximum count registers are all 16 bits wide, 16 bits of resolution are provided. Any Read or Write access to the timers will add one wait state to the minimum four-clock bus cycle, however. This is needed to synchronize and coordinate the internal data flows between the internal timers and the internal bus.

The timers have several programmable options.

- All three timers can be set to halt or continue on a terminal count.
- Timers 0 and 1 can select between internal and external clocks, alternate between MAX COUNT registers and be set to retrigger on external events.
- The timers may be programmed to cause an interrupt on terminal count.

These options are selectable via the timer mode/control word.

Timer Mode/Control Register

The mode/control register (see Figure 20) allows the user to program the specific mode of operation or check the current programmed status for any of the three integrated timers.

Table 15. Timer Control Block Format

Register Name	Register Offset		
	Tmr. 0	Tmr. 1	Tmr. 2
Mode/Control Word	56H	5EH	66H
Max Count B	54H	5CH	not present
Max Count A	52H	5AH	62H
Count Register	50H	58H	60H

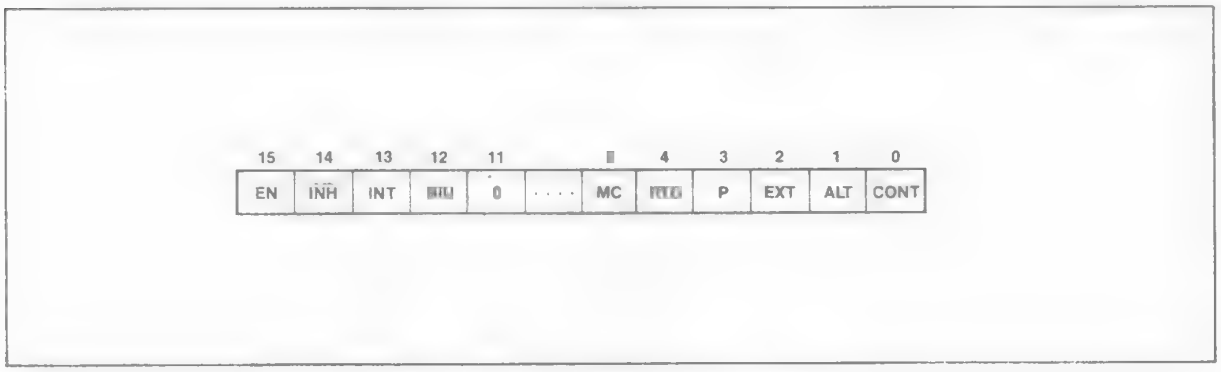

Figure 20. Timer Mode/Control Register

ALT:
The ALT bit determines which of two MAX COUNT registers is used for count comparison. If ALT = 0, register A for that timer is always used, while if ALT = 1, the comparison will alternate between register A and register B when each maximum count is reached. This alternation allows the user to change one MAX COUNT register while the other is being used, and thus provides a method of generating non-repetitive waveforms. Square waves and pulse outputs of any duty cycle are a subset of available signals obtained by not changing the final count registers. The ALT bit also determines the function of the timer output pin. If ALT is zero, the output pin will go LOW for one clock, the clock after the maximum count is reached. If ALT is one, the output pin will reflect the current MAX COUNT register being used (0/1 for B/A).

CONT:
Setting the CONT bit causes the associated timer to run continuously, while resetting it causes the timer to halt upon maximum count. If CONT = 0 and ALT =1, the timer will count to the MAX COUNT register A value, reset, count to the register B value, reset, and halt.

EXT:
The external bit selects between internal and external clocking for the timer. The external signal may be asynchronous with respect to the 80186 clock. If this bit is set, the timer will count LOW-to-HIGH transitions on the input pin. If cleared, it will count an internal clock while using the input pin for control. In this mode, the function of the external pin is defined by the RTG bit. The maximum input to output transition latency time may be as much as 6 clocks. However, clock inputs may be pipelined as closely together as every 4 clocks without losing clock pulses.

P:
The prescaler bit is ignored unless internal clocking has been selected (EXT = 0). If the P bit is a zero, the timer will count at one-fourth the internal CPU clock rate. If the P bit is a one, the output of timer 2 will be used as a clock for the timer. Note that the user must initialize and start timer 2 to obtain the prescaled clock.

RTG:
Retrigger bit is only active for internal clocking (EXT = 0). In this case it determines the control function provided by the input pin.

If RTG = 0, the input level gates the internal clock on and off. If the input pin is HIGH, the timer will count; if the input pin is LOW, the timer will hold its value. As indicated previously, the input signal may be asynchronous with respect to the 80186 clock.

When RTG = 1, the input pin detects LOW-to-HIGH transitions. The first such transition starts the timer running, clearing the timer value to zero on the first clock, and then incrementing thereafter. Further transitions on the input pin will again reset the timer to zero, from which it will start counting up again. If CONT = 0, when the timer has reached maximum count, the EN bit will be cleared, inhibiting further timer activity.

EN:
The enable bit provides programmer control over the timer's RUN/HALT status. When set, the timer is enabled to increment subject to the input pin constraints in the internal clock mode (discussed previously). When cleared, the timer will be inhibited from counting. All input pin transitions during the time EN is zero will be ignored. If CONT is zero, the EN bit is automatically cleared upon maximum count.

INH:
The inhibit bit allows for selective updating of the enable (EN) bit. If INH is a one during the write to the mode/control word, then the state of the EN bit will be modified by the write. If INH is a zero during the write, the EN bit will be unaffected by the operation. This bit is not stored; it will always be a 0 on a read.

INT:
When set, the INT bit enables interrupts from the timer, which will be generated on every terminal count. If the timer is configured in dual MAX COUNT register mode, an interrupt will be generated each time the value in MAX COUNT register A is reached, and each time the value in MAX COUNT register B is reached. If this enable bit is cleared after the interrupt request has been generated, but before a pending interrupt is serviced, the interrupt request will still be in force. (The request is latched in the Interrupt Controller.)

MC:
The Maximum Count bit is set whenever the timer reaches its final maximum count value. If the timer is configured in dual MAX COUNT register mode, this bit will be set each time the value in MAX COUNT register A is reached, and each time the value in MAX COUNT register B is reached. This bit is set regardless of the timer's interrupt-enable bit. The MC bit gives the user the ability to monitor timer status through software instead of through interrupts. Programmer Intervention is required to clear this bit.

RIU:
The Register In Use bit indicates which MAX COUNT register is currently being used for comparison to the timer count value. A zero value indicates register A. The RIU bit cannot be written, i.e., its value is not affected when the control register is written. It is always cleared when the ALT bit is zero.

Not all mode bits are provided for timer 2. Certain bits are hardwired as indicated below:

ALT = 0, EXT = 0, P = 0, RTG = 0, RIU = 0

Count Registers

Each of the three timers has a 16-bit count register. The current contents of this register may be read or written by the processor at any time. If the register is written into while the timer is counting, the new value will take effect in the current count cycle.

Max Count Registers

Timers 0 and 1 have two MAX COUNT registers, while timer 2 has a single MAX COUNT register. These contain the number of events the timer will count. In timers 0 and 1, the MAX COUNT register used can alternate between the two max count values whenever the current maximum count is reached. The condition which causes a timer to reset is equivalent between the current count value and the max count being used. This means that if the count is changed to be above the max count value, or if the max count value is changed to be below the current value, the timer will not reset to zero, but rather will count to its maximum value, "wrap around" to zero, then count until the max count is reached.

Timers and Reset

Upon RESET, the Timers will perform the following actions:

- All EN (Enable) bits are reset preventing timer counting.
- All SEL (Select) bits are reset to zero. This selects MAX COUNT register A, resulting in the Timer Out pins going HIGH upon RESET.

INTERRUPT CONTROLLER

The 80186 can receive interrupts from a number of sources, both internal and external. The internal interrupt controller serves to merge these requests on a priority basis, for individual service by the CPU.

Internal interrupt sources (Timers and DMA channels) can be disabled by their own control registers or by mask bits within the interrupt controller. The 80186 interrupt controller has its own control registers that set the mode of operation for the controller.

The interrupt controller will resolve priority among requests that are pending simultaneously. Nesting is provided so interrupt service routines for lower priority interrupts may themselves be interrupted by higher priority interrupts. A block diagram of the interrupt controller is shown in Figure 21.

The interrupt controller has a special iRMX 86 compatibility mode that allows the use of the 80186 within the iRMX 86 operating system interrupt structure. The controller is set in this mode by setting bit 14 in the peripheral control block relocation register (see iRMX 86 Compatibility Mode section). In this mode, the internal 80186 interrupt controller functions as a "slave" controller to an external "master" controller. Special initialization software must be included to properly set up the 80186 interrupt controller in iRMX 86 mode.

MASTER MODE OPERATION

Interrupt Controller External Interface

For external interrupt sources, five dedicated pins are provided. One of these pins is dedicated to NMI, non-maskable interrupt. This is typically used for power-fail interrupts, etc. The other four pins may function either as four interrupt input lines with internally generated interrupt vectors, as an interrupt line and an interrupt acknowledge line (called the "cascade mode") along with two other input lines with internally generated interrupt vectors, or as two interrupt input lines and two dedicated interrupt acknowledge ouput lines. When the interrupt lines are configured in cascade mode, the 80186 interrupt controller will not generate internal interrupt vectors.

External sources in the cascade mode use externally generated interrupt vectors. When an interrupt is acknowledged, two $\overline{\text{INTA}}$ cycles are initiated and the vector is read into the 80186 on the second cycle. The capability to interface to external 8259A programmable interrupt controllers is thus provided when the inputs are configured in cascade mode.

Interrupt Controller Modes of Operation

The basic modes of operation of the interrupt controller in master mode are similar to the 8259A. The interrupt controller responds identically to internal interrupts in all three modes: the difference is only in the interpretation of function of the four external interrupt pins. The interrupt controller is set into one of these three modes by programming the correct bits in the INT0 and INT1 control registers. The modes of interrupt controller operation are as follows:

Fully Nested Mode

When in the fully nested mode four pins are used as direct interrupt requests. The vectors for these four inputs are generated internally. An in-service bit is provided for every interrupt source. If a lower-priority device requests an interrupt while the in-service bit (IS) is set, no interrupt will be generated by the interrupt controller. In addition, if another interrupt request occurs from the same interrupt source while the inservice bit is set, no interrupt will be generated by the interrupt controller. This allows interrupt service routines to operate with interrupts enabled without being themselves interrupted by lower-priority interrupts. Since interrupts are enabled, higher-priority interrupts will be serviced.

When a service routine is completed, the proper IS bit must be reset by writing the proper pattern to the EOI register. This is required to allow subsequent interrupts from this interrupt source and to allow servicing of lower-priority interrupts. An EOI command is issued at the end of the service routine just before the issuance of the return from interrupt instruction. If the fully nested structure has been upheld, the next highest-priority source with its IS bit set is then serviced.

Cascade Mode

The 80186 has four interrupt pins and two of them have dual functions. In the fully nested mode the four pins are used as direct interrupt inputs and the corresponding vectors are generated internally. In the cascade mode, the four pins are configured into interrupt input-dedicated acknowledge signal pairs. The interconnection is shown in Figure 22. INT0 is an interrupt input interfaced to an 8259A, while INT2/$\overline{\text{INTA0}}$ serves as the dedicated interrupt acknowledge signal to that peripheral. The same is true for INT1 and INT3/$\overline{\text{INTA1}}$. Each pair can selectively be placed in the cascade or non-cascade mode by programming the proper value into INT0 and INT1 control registers. The use of the dedicated acknowledge signals eliminates the need for the use of external logic to generate $\overline{\text{INTA}}$ and device select signals.

The primary cascade mode allows the capability to serve up to 128 external interrupt sources through the use of external master and slave 8259As. Three levels of priority are created, requiring priority resolution in the 80186 interrupt controller, the master 8259As, and the slave 8259As. If an external interrupt is serviced, one IS bit is set at each of these levels. When the interrupt service routine is completed, up to three end-of-interrupt commands must be issued by the programmer.

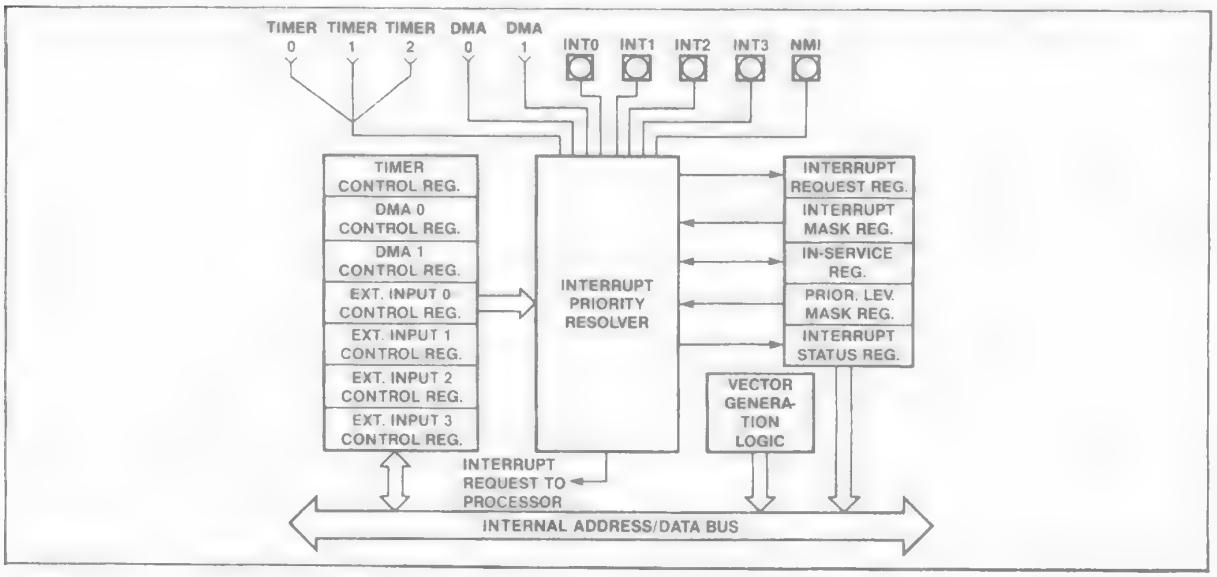

Figure 21. Interrupt Controller Block Diagram

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Special Fully Nested Mode
This mode is entered by setting the SFNM bit in INT0 or INT1 control register. It enables complete nestability with external 8259A masters. Normally, an interrupt request from an interrupt source will not be recognized unless the in-service bit for that source is reset. If more than one interrupt source is connected to an external interrupt controller, all of the interrupts will be funneled through the same 80186 interrupt request pin. As a result, if the external interrupt controller receives a higher-priority interrupt, its interrupt will not be recognized by the 80186 controller until the 80186 in-service bit is reset. In special fully nested mode, the 80186 interrupt controller will allow interrupts from an external pin regardless of the state of the in-service bit for an interrupt source in order to allow multiple interrupts from a single pin. An in-service bit will continue to be set, however, to inhibit interrupts from other lower-priority 80186 interrupt sources.

Special procedures should be followed when resetting IS bits at the end of interrupt service routines. Software polling of the external master's IS register is required to determine if there is more than one bit set. If so, the IS bit in the 80186 remains active and the next interrupt service routine is entered.

Operation in a Polled Environment

The controller may be used in a polled mode if interrupts are undesirable. When polling, the processor disables interrupts and then polls the interrupt controller whenever it is convenient. Polling the interrupt controller is accomplished by reading the Poll Word (Figure 31). Bit 15 in the poll word indicates to the processor that an interrupt of high enough priority is requesting service. Bits 0–4 indicate to the processor the type vector of the highest-priority source requesting service. Reading the Poll Word causes the In-Service bit of the highest-priority source to be set.

It is desirable to be able to read the Poll Word information without guaranteeing service of any pending interrupt, i.e., not set the indicated in-service bit. The 80186 provides a Poll Status Word in addition to the conventional Poll Word to allow this to be done. Poll Word information is duplicated in the Poll Status Word, but reading the Poll Status Word does not set the associated in-service bit. These words are located in two adjacent memory locations in the register file.

Master Mode Features

Programmable Priority
The user can program the interrupt sources into any of eight different priority levels. The programming is done by placing a 3-bit priority level (0–7) in the control register of each interrupt source. (A source with a priority level of 4 has higher priority over all priority levels from 5 to 7. Priority registers containing values lower than 4 have greater priority.) All interrupt sources have preprogrammed default priority levels (see Table 4).

If two requests with the same programmed priority level are pending at once, the priority ordering scheme shown in Table 4 is used. If the serviced interrupt routine reenables interrupts, it allows other requests to be serviced.

End-of-Interrupt Command
The end-of-interrupt (EOI) command is used by the programmer to reset the In-Service (IS) bit when an interrupt service routine is completed. The EOI command is issued by writing the proper pattern to the EOI register. There are two types of EOI commands, specific and nonspecific. The nonspecific command does not specify which IS bit is reset. When issued, the interrupt controller automatically resets the IS bit of the highest priority source with an active service routine. A specific EOI command requires that the programmer send the interrupt vector type to the interrupt controller indicating which source's IS bit is to be reset. This command is used when the fully nested structure has been disturbed or the highest priority IS bit that was set does not belong to the service routine in progress.

Trigger Mode
The four external interrupt pins can be programmed in either edge- or level-trigger mode. The control register for each external source has a level-trigger mode (LTM) bit. All interrupt inputs are active HIGH. In the edge sense mode or the level-trigger mode, the interrupt request must remain active (HIGH) until the interrupt request is acknowledged by the 80186 CPU. In the edge-sense mode, if the level remains high after the interrupt is acknowledged, the input is disabled and no further requests will be generated. The input level must go LOW for at least one clock cycle to reenable the input. In the level-trigger mode, no such provision is made: holding the interrupt input HIGH will cause continuous interrupt requests.

Interrupt Vectoring
The 80186 Interrupt Controller will generate interrupt vectors for the integrated DMA channels and the integrated Timers. In addition, the Interrupt Controller will generate interrupt vectors for the external interrupt lines if they are not configured in Cascade or Special Fully Nested Mode. The interrupt vectors generated are fixed and cannot be changed (see Table 4).

Interrupt Controller Registers

The Interrupt Controller register model is shown in Figure 23. It contains 15 registers. All registers can both be read or written unless specified otherwise.

In-Service Register
This register can be read from or written into. The format is shown in Figure 24. It contains the In-Service bit for each of the interrupt sources. The In-Service bit is set to indicate that a source's service routine is in progress. When an In-Service bit is set, the interrupt controller will not generate interrupts to the CPU when it receives interrupt requests from devices with a lower programmed priority level. The TMR bit is the In-Service bit for all three timers; the D0 and D1 bits are the In-Service bits for the two DMA channels; the I0–I3 are the In-Service bits for the external interrupt pins. The IS bit is set when the processor acknowledges an interrupt request either by an interrupt acknowledge or by reading the poll register. The IS bit is reset at the end of the interrupt service routine by an end-of-interrupt command issued by the CPU.

Interrupt Request Register
The internal interrupt sources have interrupt request bits inside the interrupt controller. The format of this register is shown in Figure 24. A read from this register yields the status of these bits. The TMR bit is the logical OR of all timer interrupt requests. D0 and D1 are the interrupt request bits for the DMA channels.

The state of the external interrupt input pins is also indicated. The state of the external interrupt pins is not a stored condition inside the interrupt controller, therefore the external interrupt bits cannot be written. The external interrupt request bits show exactly when an interrupt request is given to the interrupt controller, so if edge-triggered mode is selected, the bit in the register will be HIGH only after an inactive-to-active transition. For internal interrupt sources, the register bits are set when a request arrives and are reset when the processor acknowledges the requests.

Mask Register
This is a 16-bit register that contains a mask bit for each interrupt source. The format for this register is shown in Figure 24. A one in a bit position corresponding to a particular source serves to mask the source from generating interrupts. These mask bits are the exact same bits which are used in the individual control registers; programming a mask bit using the mask register will also change this bit in the individual control registers, and vice versa.

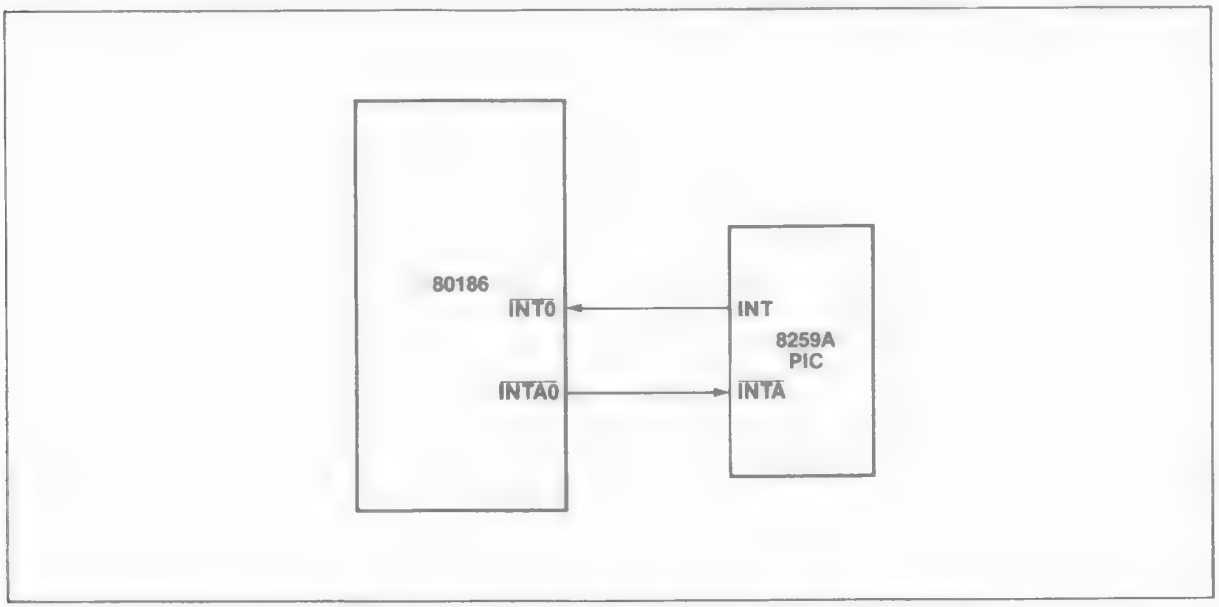

Figure 22. Cascade Mode Interrupt Connection

	OFFSET
INT3 CONTROL REGISTER	3EH
INT2 CONTROL REGISTER	[illegible]
INT1 CONTROL REGISTER	[illegible]
INT0 CONTROL REGISTER	[illegible]
DMA 1 CONTROL REGISTER	36H
DMA 0 CONTROL REGISTER	[illegible]
TIMER CONTROL REGISTER	[illegible]
INTERRUPT STATUS REGISTER	30H
INTERRUPT REQUEST REGISTER	[illegible]
IN-SERVICE REGISTER	[illegible]
PRIORITY MASK REGISTER	[illegible]
MASK REGISTER	[illegible]
POLL STATUS REGISTER	26H
POLL REGISTER	[illegible]
EOI REGISTER	22H

Figure 23. Interrupt Controller Registers (Non-iRMX 86 Mode)

Priority Mask Register

This register is used to mask all interrupts below particular interrupt priority levels. The format of this register is shown in Figure 25. The code in the lower three bits of this register inhibits interrupts of priority lower (a higher priority number) than the code specified. For example, 100 written into this register masks interrupts of level five (101), six (110), and seven (111). The register is reset to seven (111) upon RESET so all interrupts are unmasked.

Interrupt Status Register

This register contains general interrupt controller status information. The format of this register is shown in Figure 26. The bits in the status register have the following functions:

DHLT: DMA Halt Transfer; setting this bit halts all DMA transfers. It is automatically set whenever a non-maskable interrupt occurs, and it is reset when an IRET instruction is executed. The purpose of this bit is to allow prompt service of all non-maskable interrupts. This bit may also be set by the CPU.

IRTx: These three bits represent the individual timer interrupt request bits. These bits are used to differentiate the timer interrupts, since the timer IR bit in the interrupt request register is the "OR" function of all timer interrupt requests. Note that setting any one of these three bits initiates an interrupt request to the interrupt controller.

15	14		10	9	[illegible]	7	6	[illegible]	[illegible]	3	2	1	0
0	0	• • •	0	0	0	I3	I2	I1	I0	D1	D0	0	TMR

Figure 24. In-Service, Interrupt Request, and Mask Register Formats

15	14										3	[illegible]	1	0
0	0	•	•	•	•	•	•	•	•	•	0	PRM2	PRM1	PRM0

Figure 25. Priority Mask Register Format

15	14						7	6	5	4	3	[illegible]	1	0
DHLT	0	•	•	•	•	•	0	0	0	0	0	IRT2	IRT1	IRT0

Figure 26. Interrupt Status Register Format

Timer, DMA 0, 1; Control Registers
These registers are the control words for all the internal interrupt sources. The format for these registers is shown in Figure 27. The three bit positions PR0, PR1, and PR2 represent the programmable priority level of the interrupt source. The MSK bit inhibits interrupt requests from the interrupt source. The MSK bits in the individual control registers are the exact same bits as are in the Mask Register; modifying them in the individual control registers will also modify them in the Mask Register, and vice versa.

INT0–INT3 Control Registers
These registers are the control words for the four external input pins. Figure 28 shows the format of the INT0 and INT1 Control registers; Figure 29 shows the format of the INT2 and INT3 Control registers. In cascade mode or special fully nested mode, the control words for INT2 and INT3 are not used.

The bits in the various control registers are encoded as follows:

PRO-2: Priority programming information. Highest Priority = 000, Lowest Priority = 111

LTM: Level-trigger mode bit. 1 = level-triggered; 0 = edge-triggered. Interrupt Input levels are active high. In level-triggered mode, an interrupt is generated whenever the external line is high. In edge-triggered mode, an interrupt will be generated only when this level is preceded by an inactive-to-active transition on the line. In both cases, the level must remain active until the interrupt is acknowledged.

MSK: Mask bit, 1 = mask; 0 = nonmask.

C: Cascade mode bit, 1 = cascade; 0 = direct

SFNM: Special fully nested mode bit, 1 = SFNM

EOI Register
The end of the interrupt register is a command register which can only be written into. The format of this register is shown in Figure 30. It initiates an EOI command when written to by the 80186 CPU.

The bits in the EOI register are encoded as follows:

S_X: Encoded information that specifies an interrupt source vector type as shown in Table 4. For example, to reset the In-Service bit for DMA channel 0, these bits should be set to 01010, since the vector type for DMA channel 0 is 10. Note that to reset the single In-Service bit for any of the three timers, the vector type for timer 0 (8) should be written in this register.

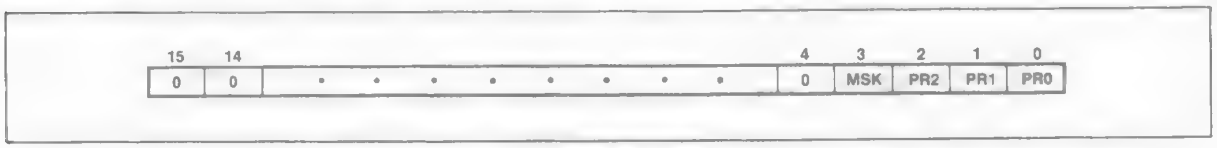

Figure 27. Timer/DMA Control Register Formats

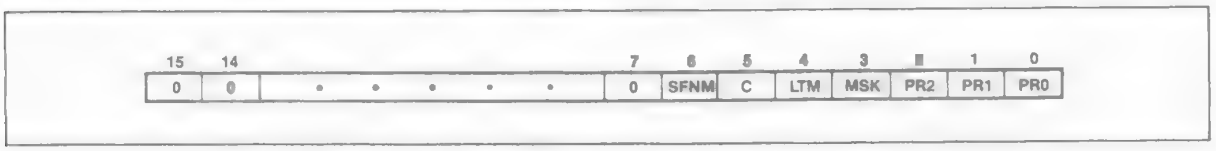

Figure 28. INT0/INT1 Control Register Formats

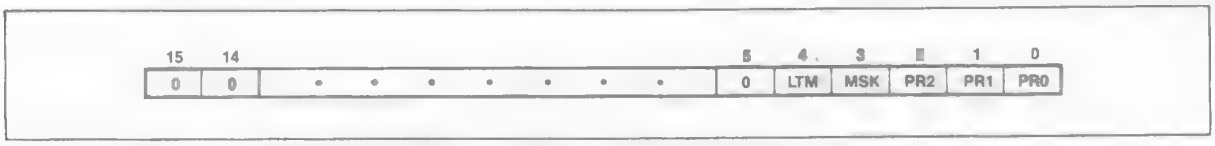

Figure 29. INT2/INT3 Control Register Formats

NSPEC/SPEC: A bit that determines the type of EOI command. Nonspecific = 1, Specific = 0.

Poll and Poll Status Registers

These registers contain polling information. The format of these registers is shown in Figure 31. They can only be read. Reading the Poll register constitutes a software poll. This will set the IS bit of the highest priority pending interrupt. Reading the poll status register will not set the IS bit of the highest priority pending interrupt; only the status of pending interrupts will be provided.

Encoding of the Poll and Poll Status register bits are as follows:

S_x: Encoded information that indicates the vector type of the highest priority interrupting source. Valid only when INTREQ = 1.

INTREQ: This bit determines if an interrupt request is present. Interrupt Request = 1; no Interrupt Request = 0.

iRMX 86 COMPATIBILITY MODE

This mode allows iRMX 86-80186 compatibility. The interrupt model of iRMX 86 requires one master and multiple slave 8259As in cascaded fashion. When iRMX mode is used, the internal 80186 interrupt controller will be used as a slave controller to an external master interrupt controller. The internal 80186 resources will be monitored through the internal interrupt controller, while the external controller functions as the system master interrupt controller.

Upon reset, the 80186 interrupt controller will be in the non-iRMX 86 mode of operation. To set the controller in the iRMX 86 mode, bit 14 of the Relocation Register should be set.

Because of pin limitations caused by the need to interface to an external 8259A master, the internal interrupt controller will no longer accept external inputs. There are however, enough 80186 interrupt controller inputs (internally) to dedicate one to each timer. In this mode, each timer interrupt source has its own mask bit, IS bit, and control word.

The iRMX 86 operating system requires peripherals to be assigned fixed priority levels. This is incompatible with the normal operation of the 80186 interrupt controller. Therefore, the initialization software must program the proper priority levels for each source. The required priority levels for the internal interrupt sources in iRMX mode are shown in Table 16.

Table 16. Internal Source Priority Level

Priority Level	Interrupt Source
0	Timer 0
1	(reserved)
2	DMA 0
3	DMA 1
4	Timer 1
5	Timer 2

These level assignments must remain fixed in the iRMX 86 mode of operation.

iRMX 86 Mode External Interface

The configuration of the 80186 with respect to an external 8259A master is shown in Figure 32. The INT0 input is used as the 80186 CPU interrupt input. INT3 functions as an output to send the 80186 slave-interrupt-request to one of the 8 master-PIC-inputs.

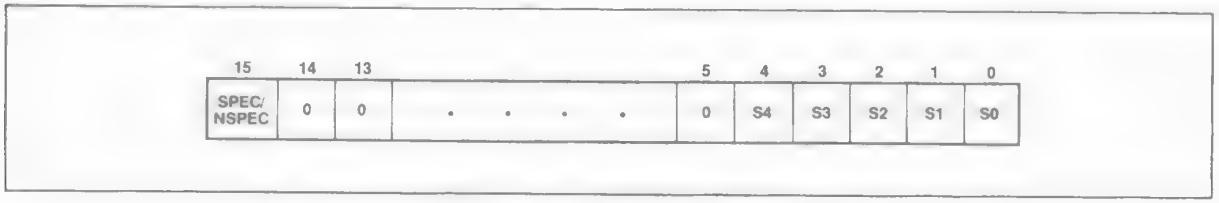

Figure 30. EOI Register Format

Figure 31. Poll Register Format

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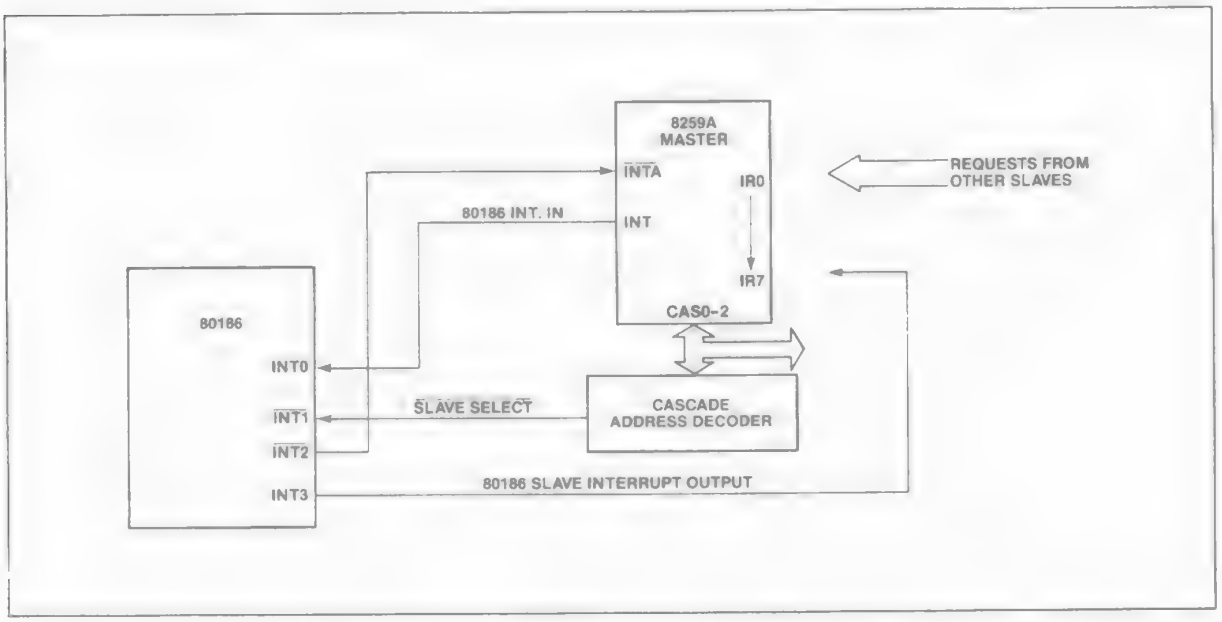

Figure 32. iRMX 86 Interrupt Controller Interconnection

Correct master-slave interface requires decoding of the slave addresses (CAS0–2). Slave 8259As do this internally. Because of pin limitations, the 80186 slave address will have to be decoded externally. $\overline{INT1}$ is used as a slave-select input. Note that the slave vector address is transferred internally, but the READY input must be supplied externally.

$\overline{INT2}$ is used as an acknowledge output, suitable to drive the $\overline{INTA}$ input of an 8259A.

Interrupt Nesting

iRMX 86 mode operation allows nesting of interrupt requests. When an interrupt is acknowledged, the priority logic masks off all priority levels except those with equal or higher priority.

Vector Generation in the iRMX 86 Mode

Vector generation in iRMX mode is exactly like that of an 8259A slave. The interrupt controller generates an 8-bit vector which the CPU multiplies by four and uses as an address into a vector table. The significant five bits of the vector are user-programmable while the lower three bits are generated by the priority logic. These bits represent the encoding of the priority level requesting service. The significant five bits of the vector are programmed by writing to the Interrupt Vector register at offset 20H.

Specific End-of-Interrupt

In iRMX mode the specific EOI command operates to reset an in-service bit of a specific priority. The user supplies a 3-bit priority-level value that points to an in-service bit to be reset. The command is executed by writing the correct value in the Specific EOI register at offset 22H.

Interrupt Controller Registers in the iRMX 86 Mode

All control and command registers are located inside the internal peripheral control block. Figure 33 shows the offsets of these registers.

End-of-Interrupt Register

The end-of-interrupt register is a command register which can only be written. The format of this register is shown in Figure 34. It initiates an EOI command when written by the 80186 CPU.

The bits in the EOI register are encoded as follows:

L_x: Encoded value indicating the priority of the IS bit to be reset.

In-Service Register

This register can be read from or written into. It contains the in-service bit for each of the internal

interrupt sources. The format for this register is shown in Figure 35. Bit positions 2 and 3 correspond to the DMA channels; positions 0, 4, and 5 correspond to the integral timers. The source's IS bit is set when the processor acknowledges its interrupt request.

Interrupt Request Register
This register indicates which internal peripherals have interrupt requests pending. The format of this register is shown in Figure 35. The interrupt request bits are set when a request arrives from an internal source, and are reset when the processor acknowledges the request.

Mask Register
This register contains a mask bit for each interrupt source. The format for this register is shown in Figure 35. If the bit in this register corresponding to a particular interrupt source is set, any interrupts from that source will be masked. These mask bits are exactly the same bits which are used in the individual control registers, i.e., changing the state of a mask bit in this register will also change the state of the mask bit in the individual interrupt control register corresponding to the bit.

Control Registers
These registers are the control words for all the internal interrupt sources. The format of these registers is shown in Figure 36. Each of the timers and both of the DMA channels have their own Control Register.

The bits of the Control Registers are encoded as follows:

pr_x: 3-bit encoded field indicating a priority level for the source; note that each source must be programmed at specified levels.

msk: mask bit for the priority level indicated by pr_x bits.

	OFFSET
LEVEL 5 CONTROL REGISTER (TIMER 2)	[illegible]
LEVEL 4 CONTROL REGISTER (TIMER 1)	[illegible]
LEVEL 3 CONTROL REGISTER (DMA 1)	36H
LEVEL 2 CONTROL REGISTER (DMA 0)	34H
LEVEL 0 CONTROL REGISTER (TIMER 0)	[illegible]
INTERRUPT STATUS REGISTER	30H
INTERRUPT-REQUEST REGISTER	[illegible]H
IN-SERVICE REGISTER	2CH
PRIORITY-LEVEL MASK REGISTER	[illegible]AH
MASK REGISTER	28H
SPECIFIC EOI REGISTER	22H
INTERRUPT VECTOR REGISTER	[illegible]

Figure 33. Interrupt Controller Registers (iRMX 86 Mode)

15	14	13		[illegible]	7	6	5	[illegible]	[illegible]	2	1	0
0	0	0	. . . . .	0	0	0	0	0	0	[illegible]	L1	[illegible]

Figure 34. Specific EOI Register Format

15	14	13		[illegible]	7	6	[illegible]	[illegible]	[illegible]	[illegible]	1	0
0	0	0	. . . . .	0	0	0	TMR[illegible]	TMR1	D1	D0	0	TMR0

Figure 35. In-Service, Interrupt Request, and Mask Register Format

Interrupt Vector Register
This register provides the upper five bits of the interrupt vector address. The format of this register is shown in Figure 37. The interrupt controller itself provides the lower three bits of the interrupt vector as determined by the priority level of the interrupt request.
The format of the bits in this register is:
t_x: 5-bit field indicating the upper five bits of the vector address.

Priority-Level Mask Register
This register indicates the lowest priority-level interrupt which will be serviced.
The encoding of the bits in this register is:
m_x: 3-bit encoded field indication priority-level value. All levels of lower priority will be masked.

Interrupt Status Register
This register is defined exactly as in Non-iRMX Mode. (See Fig. 26.)

Interrupt Controller and Reset

Upon RESET, the interrupt controller will perform the following actions:

- All SFNM bits reset to 0, implying Fully Nested Mode.
- All PR bits in the various control registers set to 1. This places all sources at lowest priority (level 111).
- All LTM bits reset to 0, resulting in edge-sense mode.
- All Interrupt Service bits reset to 0.
- All Interrupt Request bits reset to 0.
- All MSK (Interrupt Mask) bits set to 1 (mask).
- All C (Cascade) bits reset to 0 (non-cascade).
- All PRM (Priority Mask) bits set to 1, implying no levels masked.
- Initialized to non-iRMX 86 mode.

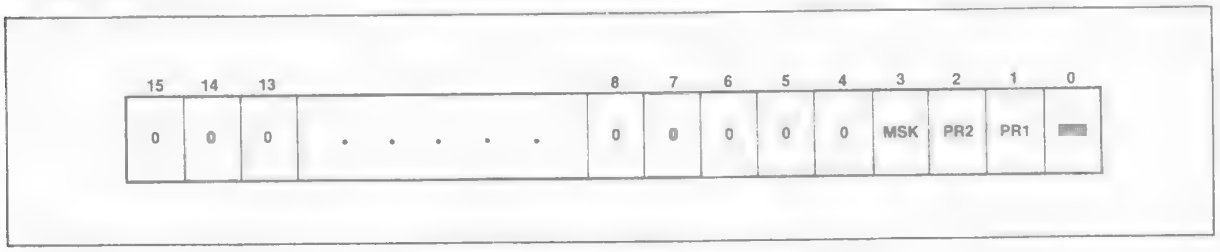

Figure 36. Control Word Format

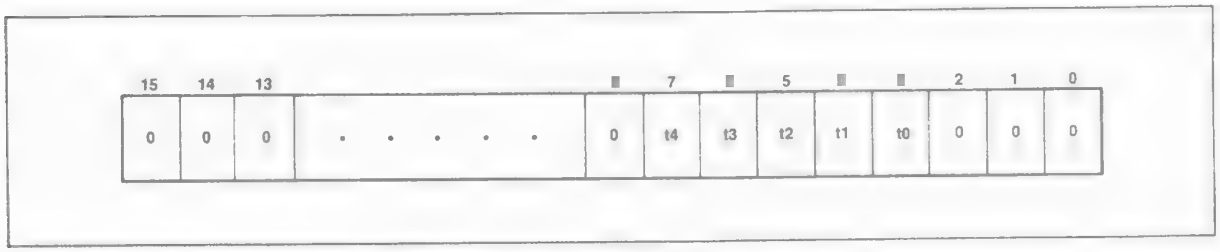

Figure 37. Interrupt Vector Register Format

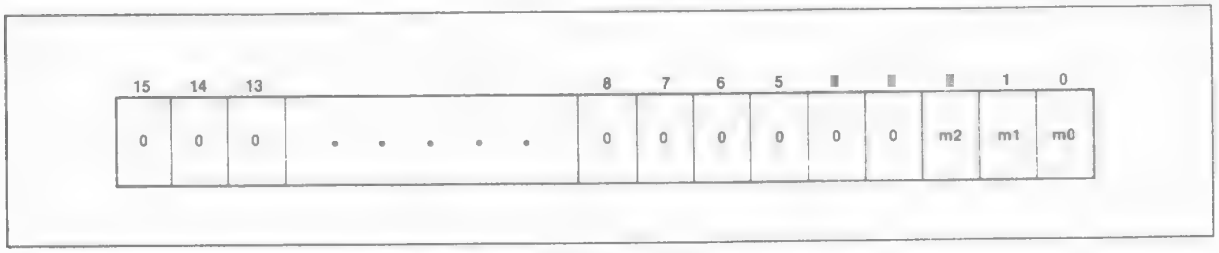

Figure 38. Priority Level Mask Register

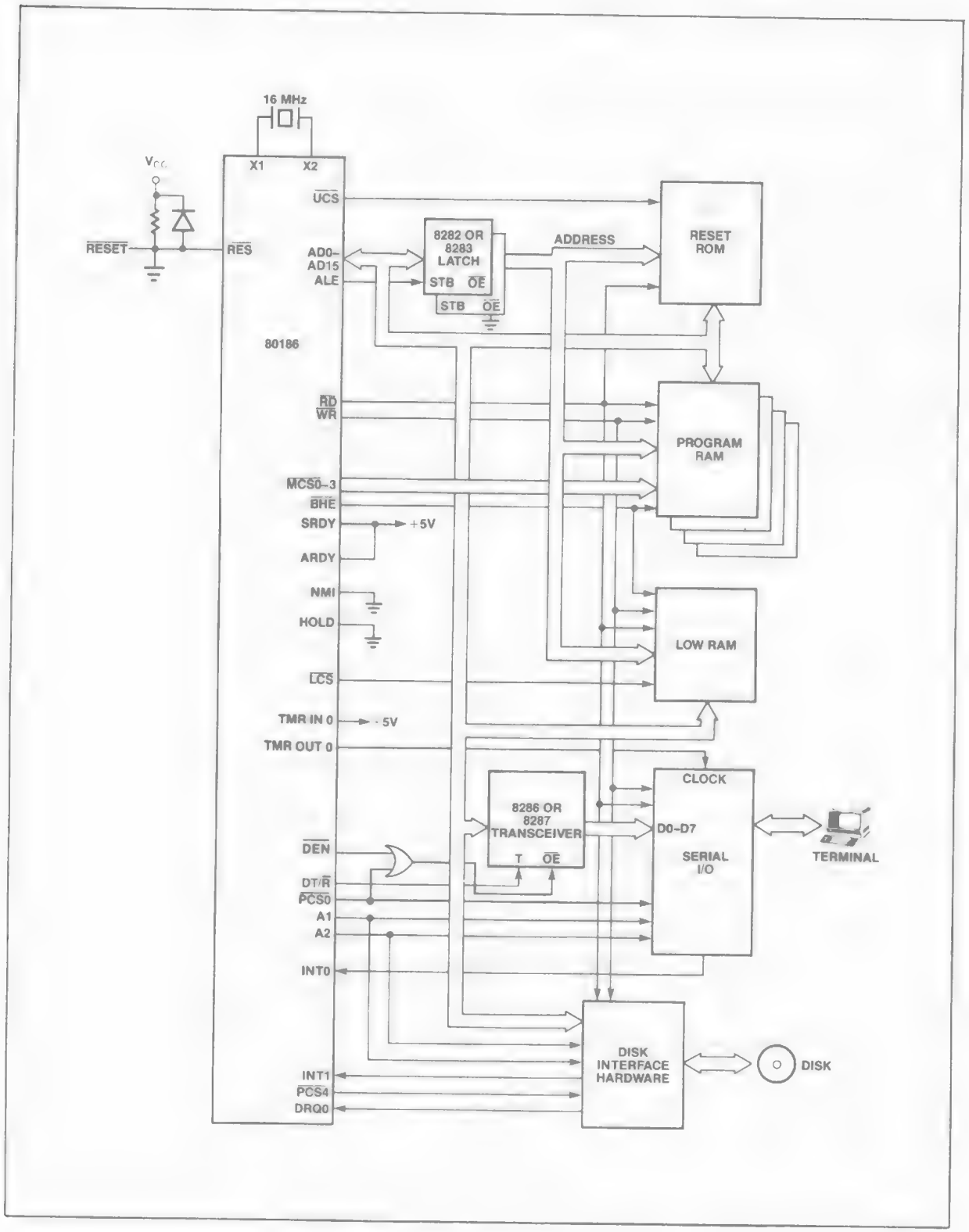

Figure 39. Typical iAPX 186 Computer

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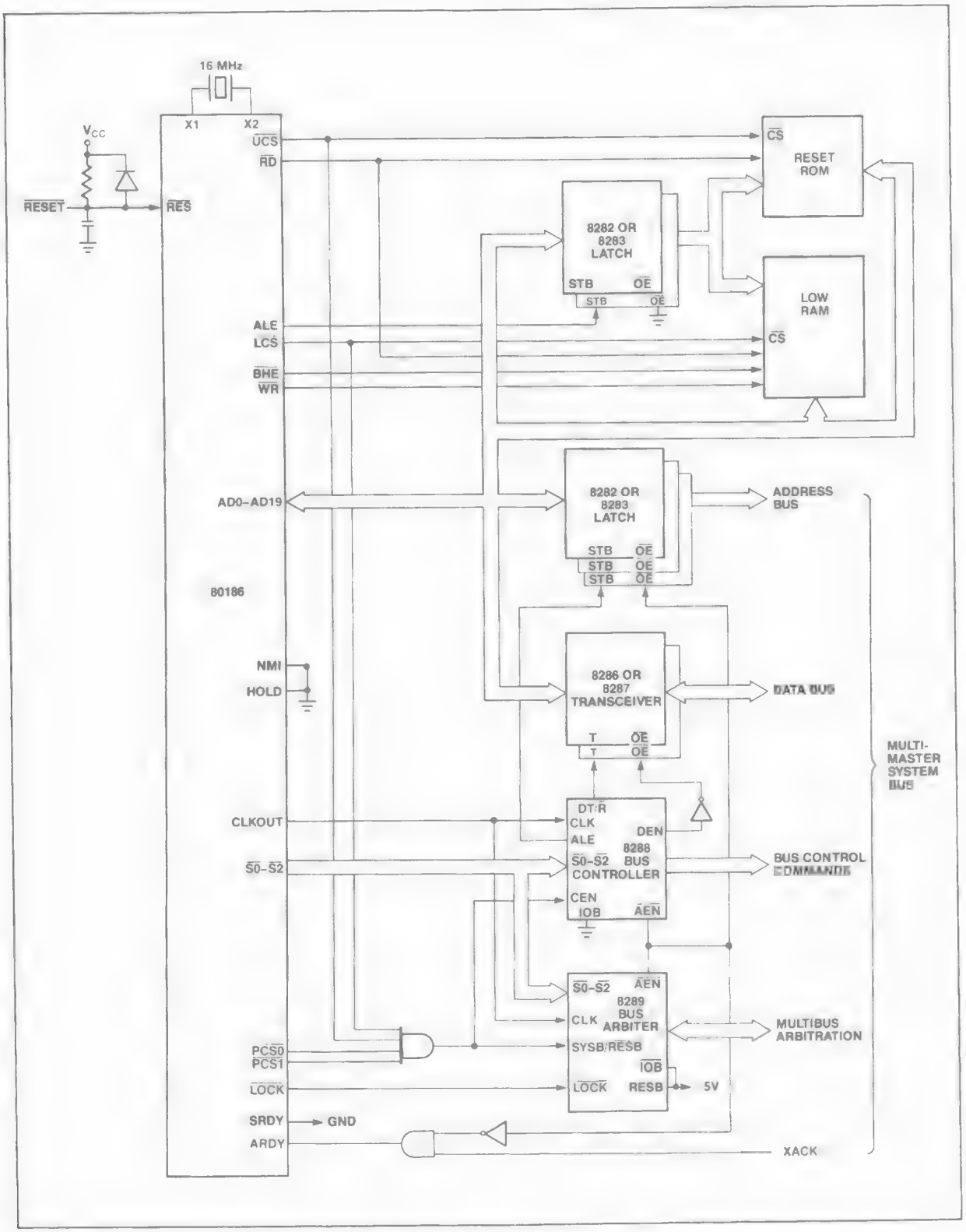

Figure 40. Typical iAPX 186 Multi-Master Bus Interface

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PACKAGE

The 80186 is housed in a 68-pin, leadless JEDEC type A hermetic chip carrier. Figure 41 illustrates the package dimensions.

NOTE: The IDT 3M Textool 68-pin JEDEC Socket is required for I²ICE™-186 operation. See Figure 42 for details.

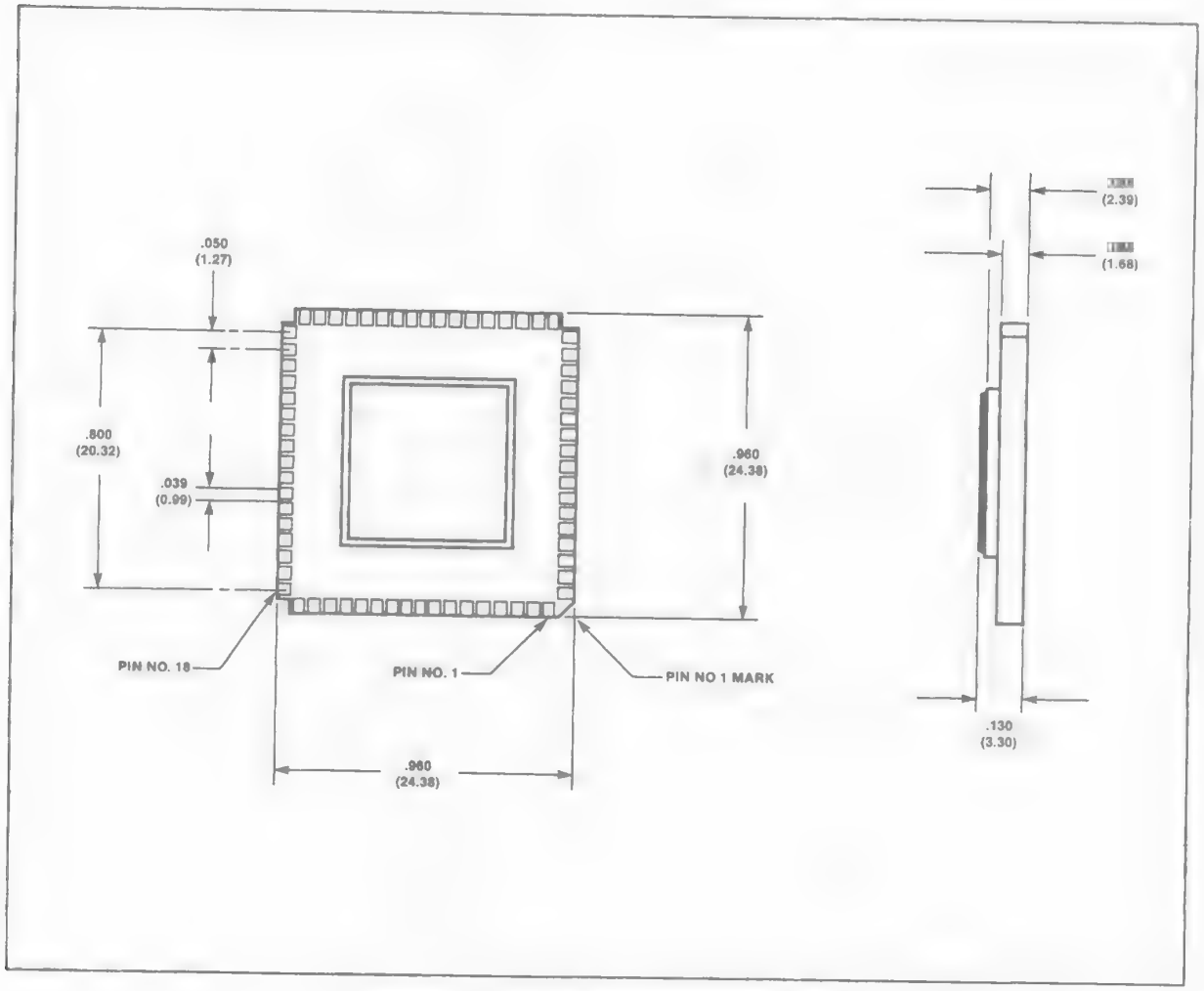

Figure 41. 80186 JEDEC Type A Package

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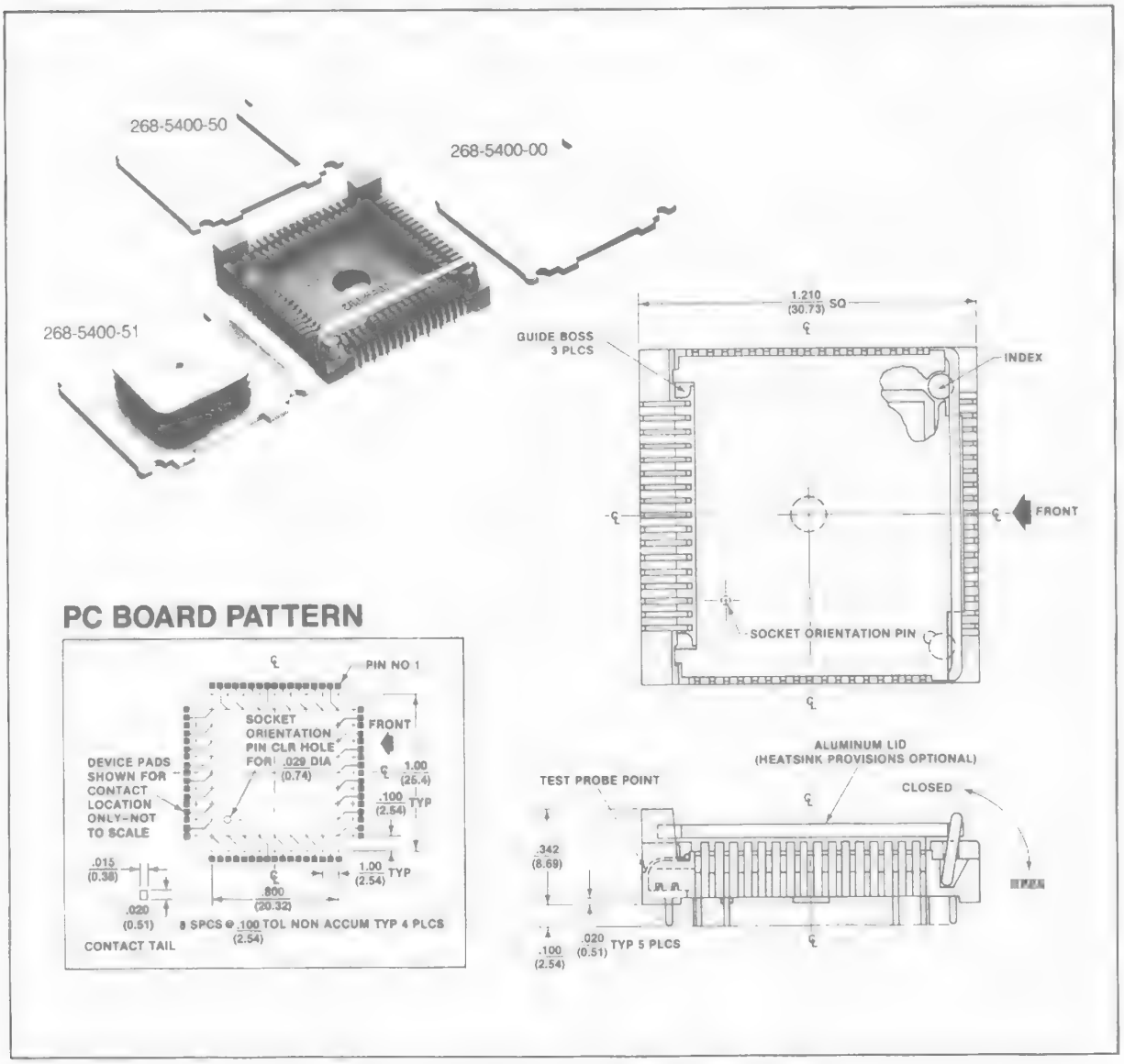

Figure 42. Textool 68 Lead Chip Carrier Socket

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ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage on Any Pin with
Respect to Ground ..... −1.0V to +7V
Power Dissipation ..... 3 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°–70°C, V_{CC} = 5V ±10%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	+0.8	Volts	
V_{IH}	Input High Voltage (All except X1 and $\overline{RES}$)	2.0	V_{CC} + 0.5	Volts	
V_{IH1}	Input High Voltage ($\overline{RES}$)	TBD	V_{CC} + 0.5	Volts	
V_{OL}	Output Low Voltage		0.45	Volts	I_a = 2.5 mA for $\overline{S0}$–$\overline{S2}$ I_a = 2.0 mA for all other outputs
V_{OH}	Output High Voltage		2.4	Volts	I_{oa} = −400 μA
I_{CC}	Power Supply Current		550	mA	T_A = 25°C
I_{LI}	Input Leakage Current		±10	μA	0V < V_{IN} < V_{CC}
I_{LO}	Output Leakage Current		±10	μA	0.45V < V_{OUT} < V_{CC}
V_{CLO}	Clock Output Low		0.6	Volts	I_a = 2.5 mA
V_{CHO}	Clock Output High	4.0		Volts	I_{oa} = −200 μA
V_{CLI}	Clock Input Low Voltage	−0.5	0.6	Volts	
V_{CHI}	Clock Input High Voltage	3.9	V_{CC} + 1.0	Volts	
C_{IN}	Input Capacitance		10	pF	
C_{IO}	I/O Capacitance		20	pF	

PIN TIMINGS

A.C. CHARACTERISTICS (T_A = 0°–70°C, V_{CC} = 5V ± 10%)

80186 Timing Requirements All Timings Measured At 1.5 Volts Unless Otherwise Noted.

Symbol	Parameter	Min.	Max.	Units	Test Conditions
TDVCL	Data in Setup (A/D)	20		ns	
TCLDX	Data in Hold (A/D)	10		ns	
TARYHCH	Asynchronous Ready (AREADY) active setup time*	20		ns	
TARYLCL	AREADY inactive setup time	35		ns	
TCHARYX	AREADY hold time	15		ns	
TSRYCL	Synchronous Ready (SREADY) transition setup time	35		ns	
TCLSRY	SREADY transition hold time	15		ns	
THVCL	HOLD Setup*	25		ns	
TINVCH	INTR, NMI, $\overline{TEST}$, TIMERIN, Setup*	25		ns	
TINVCL	DRQ0, DRQ1, Setup*	25		ns	

*To guarantee recognition at next clock.

A.C. CHARACTERISTICS (Continued)

80186 Master Interface Timing Responses

Symbol	Parameter	Min.	Max.	Units	Test Conditions
TCLAV	Address Valid Delay	10	44	ns	C_L = 20–200 pF all outputs
TCLAX	Address Hold	10		ns	
TCLAZ	Address Float Delay	TCLAX	35	ns	
TCHCZ	Command Lines Float Delay		45	ns	
TCHCV	Command Lines Valid Delay (after float)		55	ns	
TLHLL	ALE Width	TCLCL-35		ns	
TCHLH	ALE Active Delay		35	ns	
TCHLL	ALE Inactive Delay		35	ns	
TLLAX	Address Hold to ALE Inactive	TCHCL-25		ns	
TCLDV	Data Valid Delay	10	44	ns	
TCLDOX	Data Hold Time	10		ns	
TWHDX	Data Hold after $\overline{WR}$	TCLCL-40		ns	
TCVCTV	Control Active Delay1	10	70	ns	
TCHCTV	Control Active Delay2	10	55	ns	
TCVCTX	Control Inactive Delay	10	55	ns	
TAZRL	Address Float to $\overline{RD}$ Active	0		ns	
TCLRL	$\overline{RD}$ Active Delay	10	70	ns	
TCLRH	$\overline{RD}$ Inactive Delay	10	55	ns	
TRHAV	$\overline{RD}$ Inactive to Address Active	TCLCL-40		ns	
TCLHAV	HLDA Valid Delay	10	50	ns	
TRLRH	$\overline{RD}$ Width	2TCLCL-50		ns	
TWLWH	$\overline{WR}$ Width	2TCLCL-40		ns	
TAVAL	Address Valid to ALE Low	TCLCH-25		ns	
TCHSV	Status Active Delay	10	55	ns	
TCLSH	Status Inactive Delay	10	55	ns	
TCLTMV	Timer Output Delay		60	ns	100 pf max
TCLRO	Reset Delay		60	ns	
TCHQSV	Queue Status Delay		35	ns	

80186 Chip-Select Timing Responses

Symbol	Parameter	Min.	Max.	Units	Test Conditions
TCLCSV	Chip-Select Active Delay		66	ns	
TCXCSX	Chip-Select Hold from Command Inactive	35		ns	
TCHCSX	Chip-Select Inactive Delay	10	35	ns	

A.C. CHARACTERISTICS (Continued)

80186 CLKIN Requirements

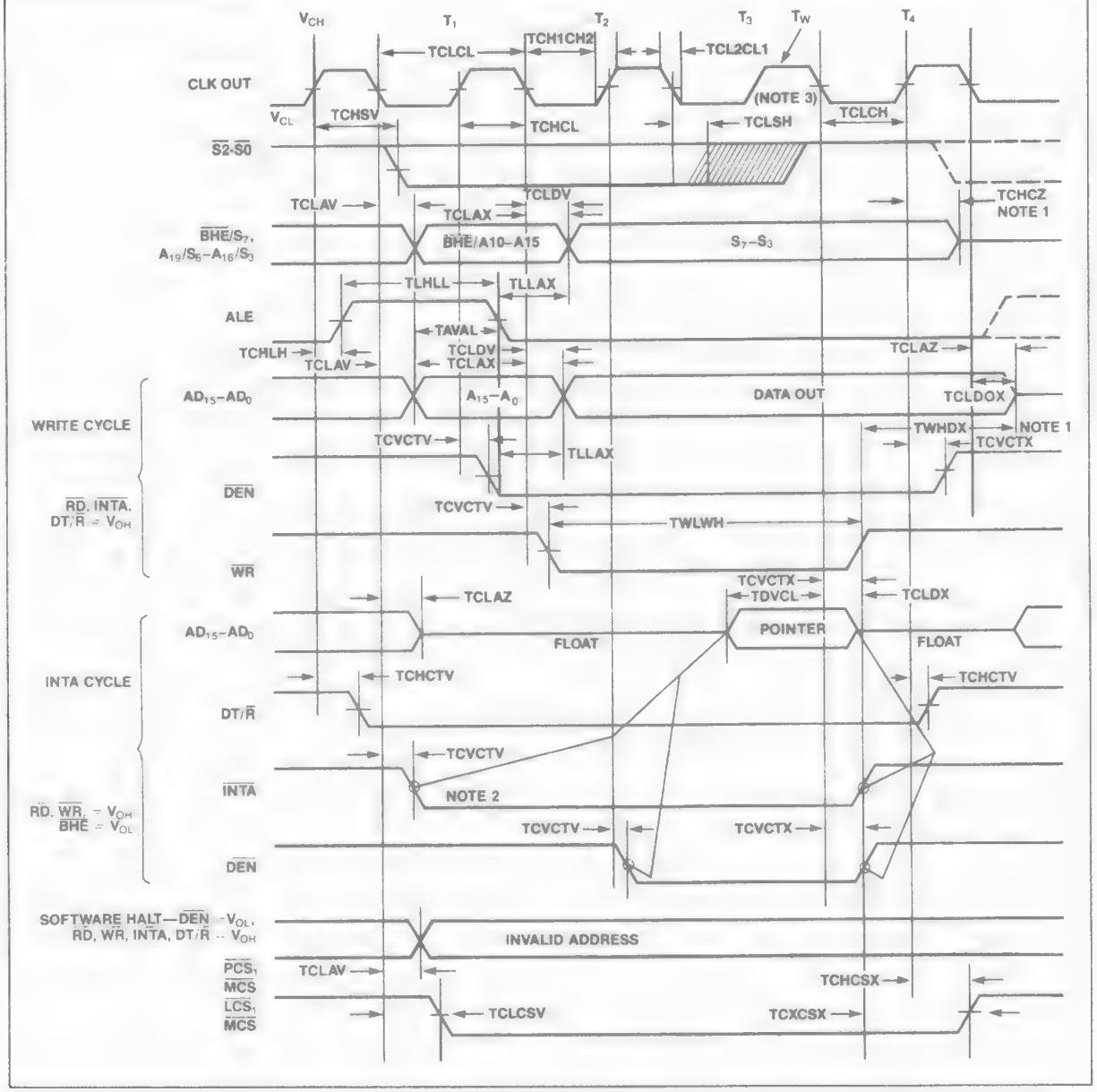
Symbol	Parameter	Min.	Max.	Units	Test Conditions
TCKIN	CLKIN Period	62.5	250	ns	
TCKHL	CLKIN Fall Time		10	ns	3.5 to 1.0 volts
TCKLH	CLKIN Rise Time		10	ns	1.0 to 3.5 volts
TCLCK	CLKIN Low Time	25		ns	1.5 volts
TCHCK	CLKIN High Time	25		ns	1.5 volts

80186 CLKOUT Timing (200 pF load)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
TCICO	CLKIN to CLKOUT Skew		50	ns	
TCLCL	CLKOUT Period	125	500	ns	
TCLCH	CLKOUT Low Time	½ TCLCL-7.5		ns	1.5 volts
TCHCL	CLKOUT High Time	½ TCLCL-7.5		ns	1.5 volts
TCH1CH2	CLKOUT Rise Time		15	ns	1.0 to 3.5 volts
TCL2CL1	CLKOUT Fall Time		15	ns	3.5 to 1.0 volts

WAVEFORMS

MAJOR CYCLE TIMING



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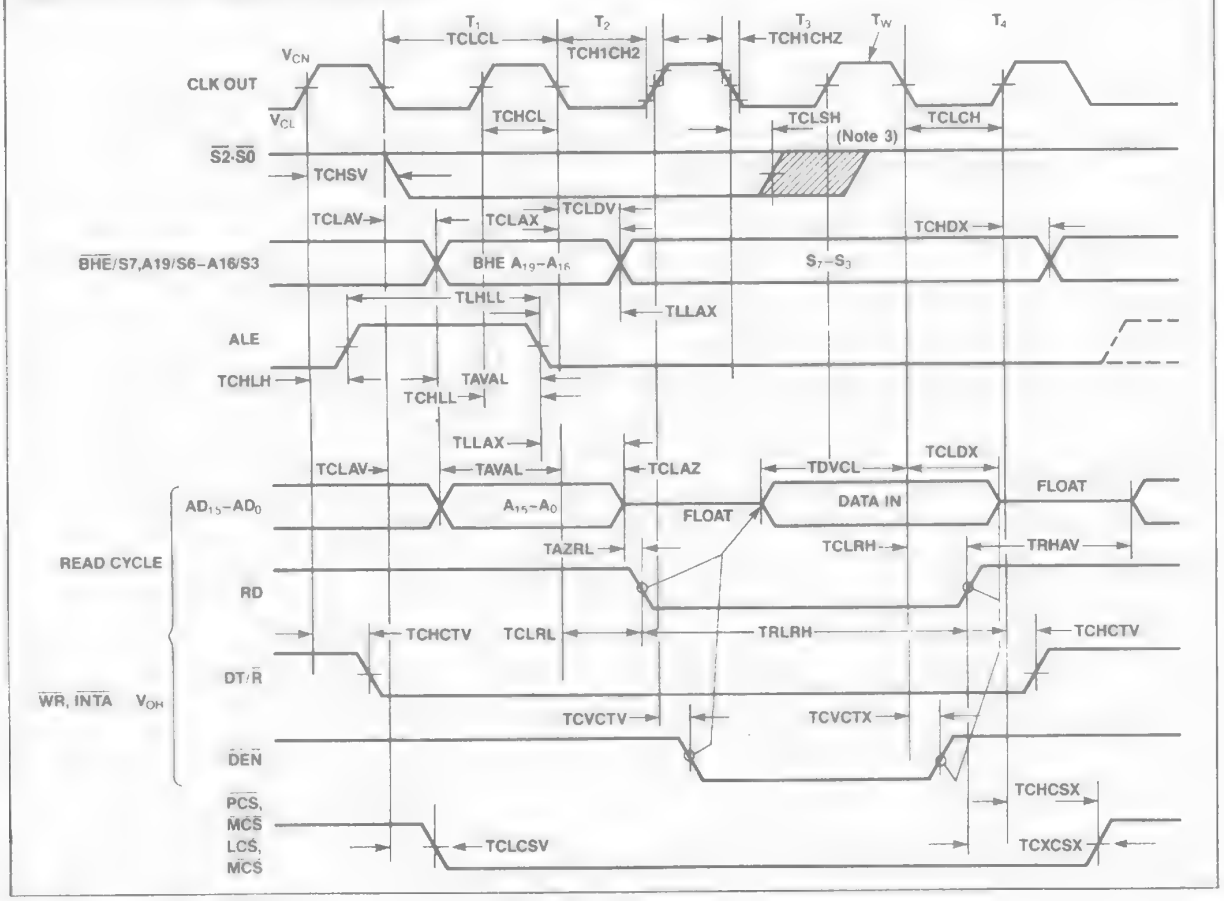
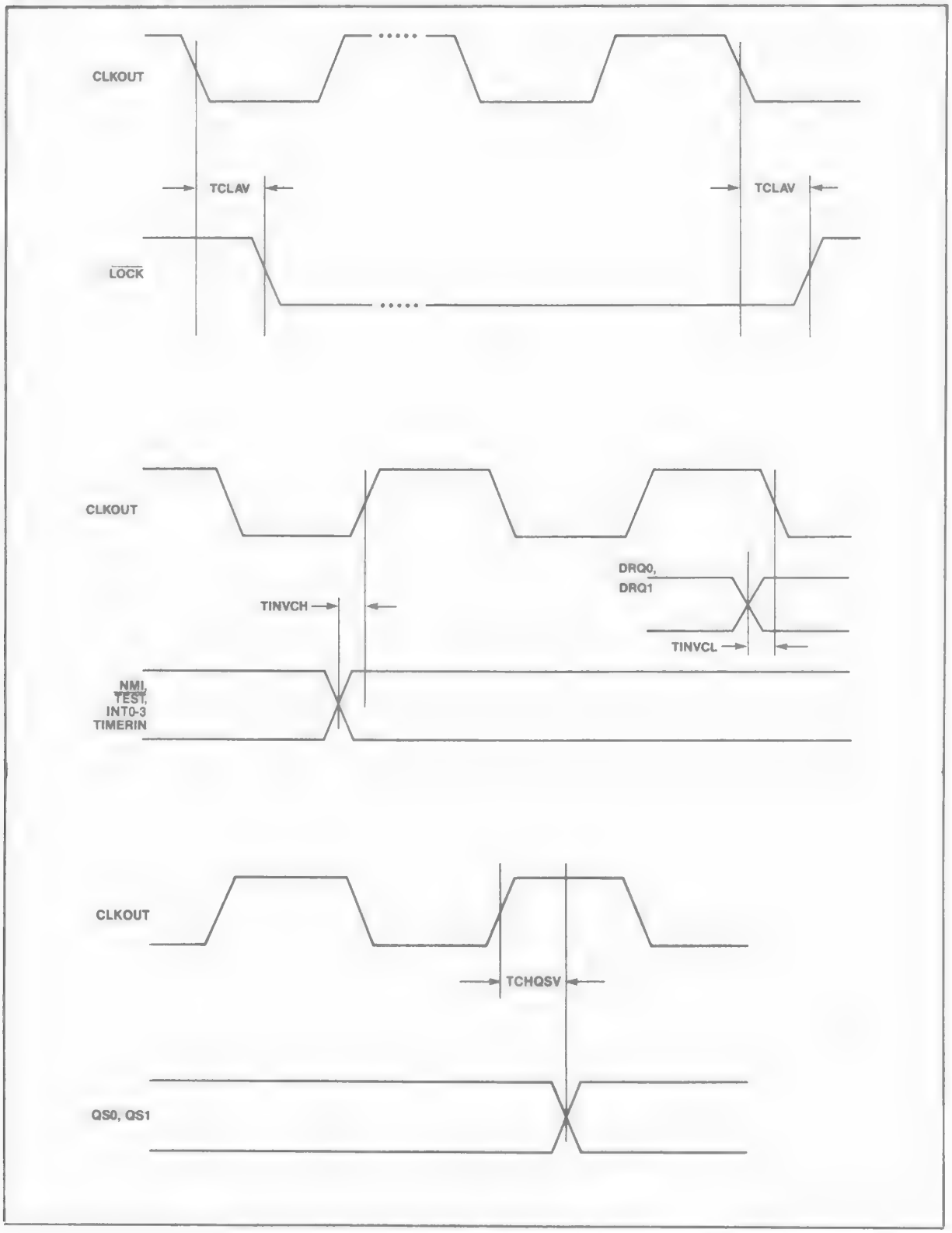
WAVEFORMS (Continued)

MAJOR CYCLE TIMING (Continued)



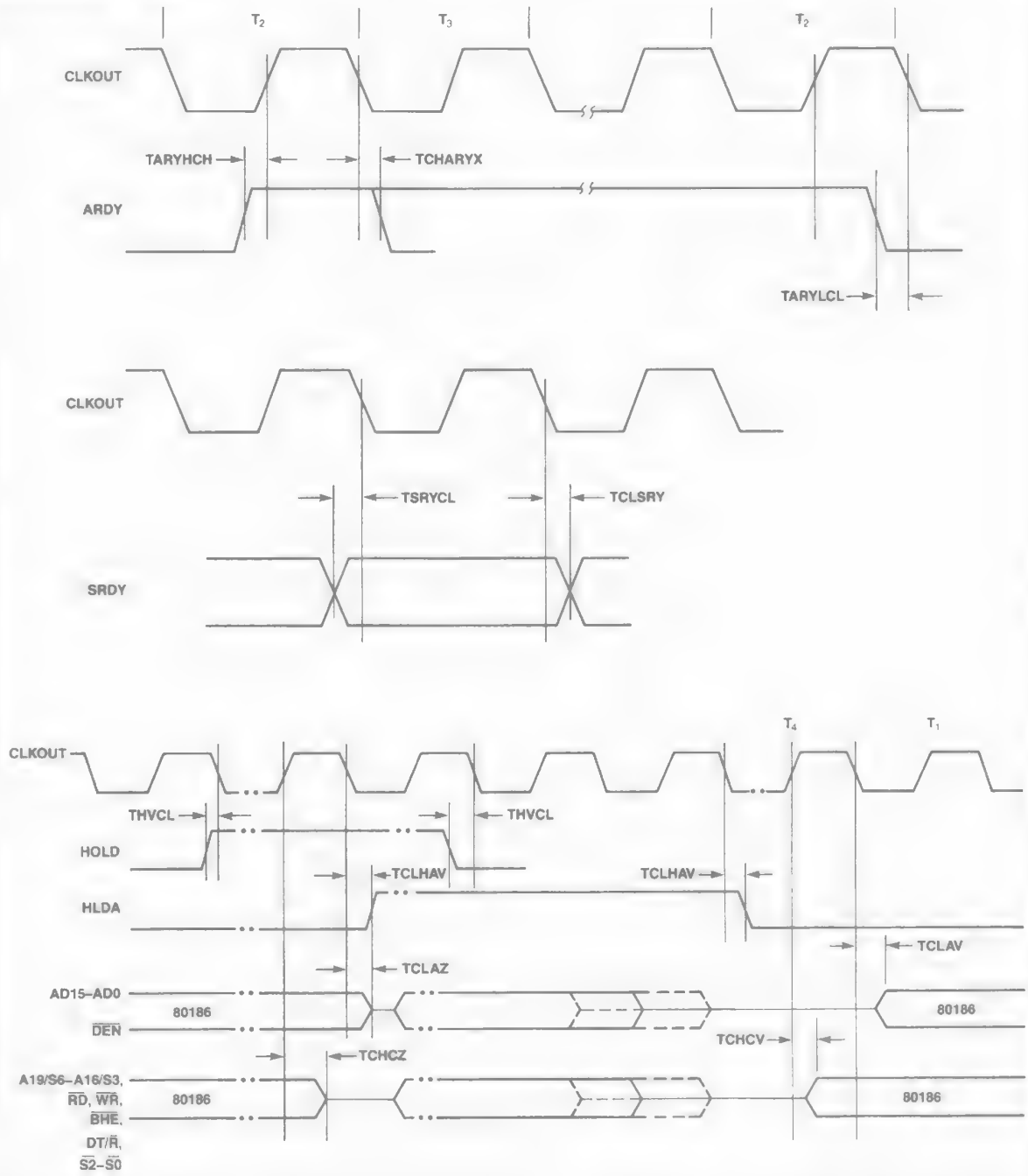
NOTES:
1. Following a Write cycle, the Local Bus is floated by the 80186 only when the 80186 enters a "Hold Acknowledge" state.
2. INTA occurs one clock later in RMX-mode
3. Status inactive just prior to T_4

WAVEFORMS (Continued)



WAVEFORMS (Continued)

HOLD-HLDA TIMING



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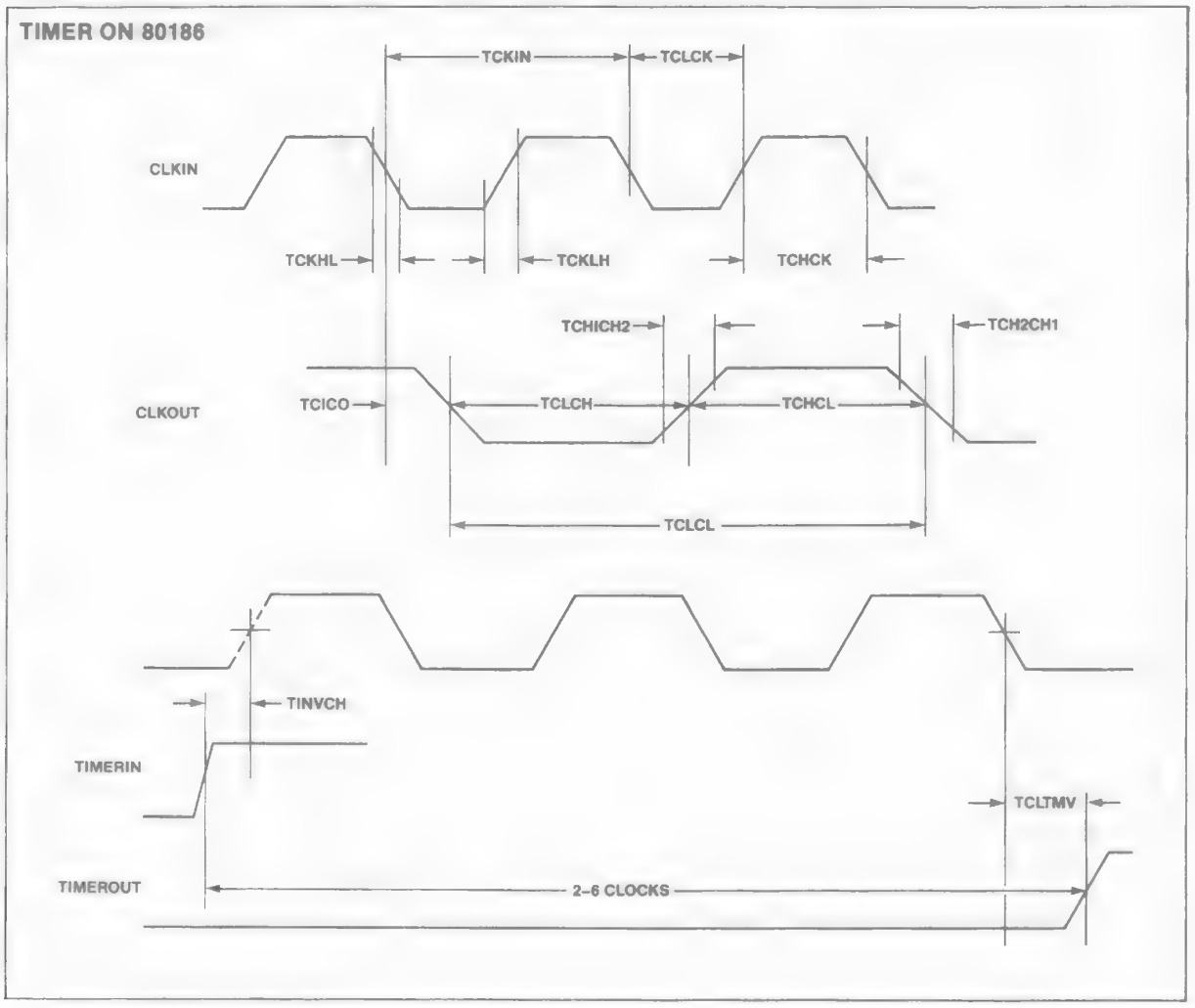
WAVEFORMS (Continued)



80186 INSTRUCTION TIMINGS

The following instruction timings represent the minimum execution time in clock cycles for each instruction. The timings given are based on the following assumptions:

- The opcode, along with any data or displacement required for execution of a particular instruction, has been prefetched and resides in the queue at the time it is needed.
- No wait states or bus HOLDS occur.
- All word-data is located on even-address boundaries.

All jumps and calls include the time required to fetch the opcode of the next instruction at the destination address.

All instructions which involve memory reference can require one (and in some cases, two) additional clocks above the minimum timings shown. This is due to the asynchronous nature of the handshake between the BIU and the Execution unit.

INSTRUCTION SET SUMMARY

FUNCTION	FORMAT				Clock Cycles	Comments
DATA TRANSFER						
MOV = Move:						
Register to Register/Memory	1 0 0 0 1 0 0 w	mod reg r/m			2/12	
Register/memory to register	1 0 0 0 1 0 1 w	mod reg r/m			2/9	
Immediate to register/memory	1 1 0 0 0 1 1 w	mod 0 0 0 r/m	data	data if w = 1	12–13	8/16-bit
Immediate to register	1 0 1 1 w reg	data	data if w = 1		3–4	8/16-bit
Memory to accumulator	1 0 1 0 0 0 0 w	addr-low	addr-high		[illegible]	
Accumulator to memory	1 0 1 0 0 0 1 w	addr-low	addr-high		[illegible]	
Register/memory to segment register	1 0 0 0 1 1 1 0	mod 0 reg r/m			2/9	
Segment register to register/memory	1 0 0 0 1 1 0 0	mod 0 reg r/m			2/11	
PUSH = Push:						
Memory	1 1 1 1 1 1 1 1	mod 1 1 0 r/m			16	
Register	0 1 0 1 0 reg				10	
Segment register	0 0 0 reg 1 1 0				9	
Immediate	0 1 1 0 1 0 s 0	data	data if s = 0		10	
PUSHA = Push All	0 1 1 0 0 0 0 0				36	
POP = Pop:						
Memory	1 0 0 0 1 1 1 1	mod 0 0 0 r/m			20	
Register	0 1 0 1 1 reg				10	
Segment register	0 0 0 reg 1 1 1	(reg ≠ 01)			[illegible]	
POPA = Pop All	0 1 1 0 0 0 0 1				51	
XCHG = Exchange:						
Register/memory with register	1 0 0 0 0 1 1 w	mod reg r/m			4/17	
Register with accumulator	1 0 0 1 0 reg				3	
IN = Input from:						
Fixed port	1 1 1 0 0 1 0 w	port			10	
Variable port	1 1 1 0 1 1 0 w				[illegible]	
OUT = Output to:						
Fixed port	1 1 1 0 0 1 1 w	port			9	
Variable port	1 1 1 0 1 1 1 w				7	
XLAT = Translate byte to AL	1 1 0 1 0 1 1 1				11	
LEA = Load EA to register	1 0 0 0 1 1 0 1	mod reg r/m			[illegible]	
LDS = Load pointer to DS	1 1 0 0 0 1 0 1	mod reg r/m	(mod ≠ 11)		18	
LES = Load pointer to ES	1 1 0 0 0 1 0 0	mod reg r/m	(mod ≠ 11)		18	
LAHF = Load AH with flags	1 0 0 1 1 1 1 1				2	
SAHF = Store AH into flags	1 0 0 1 1 1 1 0				3	
PUSHF = Push flags	1 0 0 1 1 1 0 0				[illegible]	
POPF = Pop flags	1 0 0 1 1 1 0 1				[illegible]	
SEGMENT = Segment Override:						
CS	0 0 1 0 1 1 1 0				2	
SS	0 0 1 1 0 1 1 0				[illegible]	
DS	0 0 1 1 1 1 1 0				[illegible]	
[illegible]	0 0 1 0 0 1 1 0				[illegible]	

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT				Clock Cycles	Comments
ARITHMETIC						
ADD = Add:						
Reg/memory with register to either	0 0 0 0 0 0 d w	mod reg r/m			3/10	
Immediate to register/memory	1 0 0 0 0 0 s w	mod 0 0 0 r/m	data	data if s w = 01	4/16	
Immediate to accumulator	0 0 0 0 0 1 0 w	data	data if w = 1		3/4	8/16-bit
ADC = Add with carry:						
Reg/memory with register to either	0 0 0 1 0 0 d w	mod reg r/m			3/10	
Immediate to register/memory	1 0 0 0 0 0 s w	mod 0 1 0 r/m	data	data if s w = 01	4/16	
Immediate to accumulator	0 0 0 1 0 1 0 w	data	data if w = 1		3/4	8/16-bit
INC = Increment:						
Register/memory	1 1 1 1 1 1 1 w	mod 0 0 0 r/m			3/15	
Register	0 1 0 0 0 reg				3	
SUB = Subtract:						
Reg/memory and register to either	0 0 1 0 1 0 d w	mod reg r/m			3/10	
Immediate from register/memory	1 0 0 0 0 0 s w	mod 1 0 1 r/m	data	data if s w = 0 1	4/16	
Immediate from accumulator	0 0 1 0 1 1 0 w	data	data if w = 1		3/4	8/16-bit
SBB = Subtract with borrow:						
Reg/memory and register to either	0 0 0 1 1 0 d w	mod reg r/m			3/10	
Immediate from register/memory	1 0 0 0 0 0 s w	mod 0 1 1 r/m	data	data if s w = 0 1	4/16	
Immediate from accumulator	0 0 0 1 1 1 0 w	data	data if w = 1		3/4	8/16-bit
DEC = Decrement:						
Register/memory	1 1 1 1 1 1 1 w	mod 0 0 1 r/m			3/15	
Register	0 1 0 0 1 reg				3	
CMP = Compare:						
Register/memory with register	0 0 1 1 1 0 1 w	mod reg r/m			3/10	
Register with register/memory	0 0 1 1 1 0 0 w	mod reg r/m			3/10	
Immediate with register/memory	1 0 0 0 0 0 s w	mod 1 1 1 r/m	data	data if s w = 0 1	3/10	
Immediate with accumulator	0 0 1 1 1 1 0 w	data	data if w = 1		3/4	8/16-bit
NEG = Change sign	1 1 1 1 0 1 1 w	mod 0 1 1 r/m			3	
AAA – ASCII adjust for add	0 0 1 1 0 1 1 1				[illegible]	
DAA – Decimal adjust for add	0 0 1 0 0 1 1 1				4	
AAS – ASCII adjust for subtract	0 0 1 1 1 1 1 1				7	
DAS – Decimal adjust for subtract	0 0 1 0 1 1 1 1				4	
MUL – Multiply (unsigned):	1 1 1 1 0 1 1 w	mod 1 0 0 r/m				
Register-Byte					26–28	
Register-Word					35–37	
Memory-Byte					32–34	
Memory-Word					41–43	
IMUL = Integer multiply (signed):	1 1 1 1 0 1 1 w	mod 1 0 1 r/m				
Register-Byte					25–28	
Register-Word					34–37	
Memory-Byte					31–34	
Memory-Word					40–43	
IMUL = Integer immediate multiply (signed)	0 1 1 0 1 0 s 1	mod reg r/m	data	data if s = 0	22–25/29–32	
DIV – Divide (unsigned)	1 1 1 1 0 1 1 w	mod 1 1 0 r/m				
Register-Byte					29	
Register-Word					38	
Memory-Byte					35	
Memory-Word					44	

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT				Clock Cycles	Comments
ARITHMETIC (Continued):						
IDIV - Integer divide (signed):	1 1 1 1 0 1 1 w	mod 1 1 1 r/m			44–52	
Register-Byte						
Register-Word					53–61	
Memory-Byte					50–58	
Memory-Word					59–67	
AAM - ASCII adjust for multiply	1 1 0 1 0 1 0 0	0 0 0 0 1 0 1 0			19	
AAD - ASCII adjust for divide	1 1 0 1 0 1 0 1	0 0 0 0 1 0 1 0			15	
CBW - Convert byte to word	1 0 0 1 1 0 0 0				2	
CWD - Convert word to double word	1 0 0 1 1 0 0 1				4	
LOGIC						
Shift Rotate Instructions:						
Register/Memory by 1	1 1 0 1 0 0 0 w	mod TTT r/m			2/15	
Register/Memory by CL	1 1 0 1 0 0 1 w	mod TTT r/m			5+n/17+n	
Register/Memory by Count	1 1 0 0 0 0 0 w	mod TTT r/m	count		5+n/17+n	

TTT	Instruction
0 0 0	ROL
0 0 1	ROR
0 1 0	RCL
0 1 1	RCR
1 0 0	SHL/SAL
1 0 1	SHR
1 1 1	SAR

AND = And:						
Reg/memory and register to either	0 0 1 0 0 0 d w	mod reg r/m			3/10	
Immediate to register/memory	1 0 0 0 0 0 0 w	mod 1 0 0 r/m	data	data if w = 1	4/16	
Immediate to accumulator	0 0 1 0 0 1 0 w	data	data if w = 1		3/4	8/16-bit
TEST = And function to flags, no result:						
Register/memory and register	1 0 0 0 0 1 0 w	mod reg r/m			3/10	
Immediate data and register/memory	1 1 1 1 0 1 1 w	mod 0 0 0 r/m	data	data if w = 1	4/10	
Immediate data and accumulator	1 0 1 0 1 0 0 w	data	data if w = 1		3/4	8/16-bit
OR = Or:						
Reg/memory and register to either	0 0 0 0 1 0 d w	mod reg r/m			3/10	
Immediate to register/memory	1 0 0 0 0 0 0 w	mod 0 0 1 r/m	data	data if w = 1	4/16	
Immediate to accumulator	0 0 0 0 1 1 0 w	data	data if w = 1		3/4	8/16-bit
XOR = Exclusive or:						
Reg/memory and register to either	0 0 1 1 0 0 d w	mod reg r/m			3/10	
Immediate to register/memory	1 0 0 0 0 0 0 w	mod 1 1 0 r/m	data	data if w = 1	4/16	
Immediate to accumulator	0 0 1 1 0 1 0 w	data	data if w = 1		3/4	8/16-bit
NOT = Invert register/memory	1 1 1 1 0 1 1 w	mod 0 1 0 r/m			3	
STRING MANIPULATION:						
MOVS - Move byte/word	1 0 1 0 0 1 0 w				14	
CMPS - Compare byte/word	1 0 1 0 0 1 1 w				22	
SCAS - Scan byte/word	1 0 1 0 1 1 1 w				15	
LODS - Load byte/wd to AL/AX	1 0 1 0 1 1 0 w				12	
STOS = Stor byte/wd from AL/A	1 0 1 0 1 0 1 w				10	
INS - Input byte/wd from DX port	0 1 1 0 1 1 0 w				14	
OUTS - Output byte/wd to DX port	0 1 1 0 1 1 1 w				14	

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT			Clock Cycles	Comments
STRING MANIPULATION (Continued):					
Repeated by count in CX					
MOVS Move string	1 1 1 1 0 0 1 0	1 0 1 0 0 1 0 w		8+8n	
CMPS Compare string	1 1 1 1 0 0 1 z	1 0 1 0 0 1 1 w		5+22n	
SCAS - Scan string	1 1 1 1 0 0 1 z	1 0 1 0 1 1 1 w		5+15n	
LODS Load string	1 1 1 1 0 0 1 0	1 0 1 0 1 1 0 w		6+11n	
STOS - Store string	1 1 1 1 0 0 1 0	1 0 1 0 1 0 1 w		6+9n	
INS - Input string	1 1 1 1 0 0 1 0	0 1 1 0 1 1 0 w		8+8n	
OUTS				8+8n	
CONTROL TRANSFER					
CALL = Call:					
Direct within segment	1 1 1 0 1 0 0 0	disp-low	disp-high	14	
Register memory indirect within segment	1 1 1 1 1 1 1 1	mod 0 1 0 r/m		13/19	
Direct intersegment	1 0 0 1 1 0 1 0	segment offset		23	
		segment selector			
Indirect intersegment	1 1 1 1 1 1 1 1	mod 0 1 1 r/m	(mod ≠ 11)	38	
JMP = Unconditional jump:					
Short/long	1 1 1 0 1 0 1 1	disp-low		13	
Direct within segment	1 1 1 0 1 0 0 1	disp-low	disp-high	13	
Register/memory indirect within segment	1 1 1 1 1 1 1 1	mod 1 0 0 r/m		11/17	
Direct intersegment	1 1 1 0 1 0 1 0	segment offset		13	
		segment selector			
Indirect intersegment	1 1 1 1 1 1 1 1	mod 1 0 1 r/m	(mod ≠ 11)	26	
RET = Return from CALL:					
Within segment	1 1 0 0 0 0 1 1			16	
Within seg adding immed to SP	1 1 0 0 0 0 1 0	data-low	data-high	18	
Intersegment	1 1 0 0 1 0 1 1			22	
Intersegment adding immediate to SP	1 1 0 0 1 0 1 0	data-low	data-high	25	

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT			Clock Cycles	Comments
CONTROL TRANSFER (Continued):					
JE/JZ – Jump on equal/zero	0 1 1 1 0 1 0 0	disp		4/13	13 if JMP taken 4 if JMP not taken
JL/JNGE – Jump on less/not greater or equal	0 1 1 1 1 1 0 0	disp		4/13	
JLE/JNG – Jump on less or equal/not greater	0 1 1 1 1 1 1 0	disp		4/13	
JB/JNAE – Jump on below/not above or equal	0 1 1 1 0 0 1 0	disp		4/13	
JBE/JNA – Jump on below or equal/not above	0 1 1 1 0 1 1 0	disp		4/13	
JP/JPE – Jump on parity/parity even	0 1 1 1 1 0 1 0	disp		4/13	
JO – Jump on overflow	0 1 1 1 0 0 0 0	disp		4/13	
JS – Jump on sign	0 1 1 1 1 0 0 0	disp		4/13	
JNE/JNZ – Jump on not equal/not zero	0 1 1 1 0 1 0 1	disp		4/13	
JNL/JGE – Jump on not less/greater or equal	0 1 1 1 1 1 0 1	disp		4/13	
JNLE/JG – Jump on not less or equal/greater	0 1 1 1 1 1 1 1	disp		4/13	
JNB/JAE – Jump on not below/above or equal	0 1 1 1 0 0 1 1	disp		4/13	
JNBE/JA – Jump on not below or equal/above	0 1 1 1 0 1 1 1	disp		4/13	
JNP/JPO – Jump on not par/par odd	0 1 1 1 1 0 1 1	disp		4/13	
JNO – Jump on not overflow	0 1 1 1 0 0 0 1	disp		4/13	
JNS – Jump on not sign	0 1 1 1 1 0 0 1	disp		4/13	
LOOP – Loop CX times	1 1 1 0 0 0 1 0	disp		5/15	
LOOPZ/LOOPE – Loop while zero/equal	1 1 1 0 0 0 0 1	disp		6/16	
LOOPNZ/LOOPNE – Loop while not zero/equal	1 1 1 0 0 0 0 0	disp		6/16	
JCXZ – Jump on CX zero	1 1 1 0 0 0 1 1	disp		16 / 5	JMP taken/ JMP not taken
ENTER – Enter Procedure	1 1 0 0 1 0 0 0	data-low	data-high	L	
L = 0				15	
L = 1				25	
L > 1				22 + 16(n − 1)	
LEAVE – Leave Procedure	1 1 0 0 1 0 0 1			8	
INT = Interrupt:					
Type specified	1 1 0 0 1 1 0 1	type		47	
Type 3	1 1 0 0 1 1 0 0			45	if INT. taken/ if INT. not taken
INTO = Interrupt on overflow	1 1 0 0 1 1 1 0			48/4	
IRET = Interrupt return	1 1 0 0 1 1 1 1			28	
BOUND = Detect value out of range	0 1 1 0 0 0 1 0	mod reg r/m		33–35	

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT	Clock Cycles	Comments
PROCESSOR CONTROL			
CLC = Clear carry	1 1 1 1 1 0 0 0	2	
CMC = Complement carry	1 1 1 1 0 1 0 1	2	
STC = Set carry	1 1 1 1 1 0 0 1	2	
CLD = Clear direction	1 1 1 1 1 1 0 0	2	
STD = Set direction	1 1 1 1 1 1 0 1	2	
CLI = Clear interrupt	1 1 1 1 1 0 1 0	2	
STI = Set interrupt	1 1 1 1 1 0 1 1	2	
HLT = Halt	1 1 1 1 0 1 0 0	2	
WAIT = Wait	1 0 0 1 1 0 1 1	6	if $\overline{test}$ = 0
LOCK = Bus lock prefix	1 1 1 1 0 0 0 0	2	
ESC = Processor Extension Escape	1 0 0 1 1 T T T mod LLL r/m (TTT LLL are opcode to processor extension)	6	

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

FOOTNOTES

The effective Address (EA) of the memory operand is computed according to the mod and r/m fields:

if mod = 11 then r/m is treated as a REG field
if mod = 00 then DISP = 0*, disp-low and disp-high are absent
if mod = 01 then DISP = disp-low sign-extended to 16-bits, disp-high is absent
if mod = 10 then DISP = disp-high: disp-low

if r/m = 000 then EA = (BX) + (SI) + DISP
if r/m = 001 then EA = (BX) + (DI) + DISP
if r/m = 010 then EA = (BP) + (SI) + DISP
if r/m = 011 then EA = (BP) + (DI) + DISP
if r/m = 100 then EA = (SI) + DISP
if r/m = 101 then EA = (DI) + DISP
if r/m = 110 then EA = (BP) + DISP*
if r/m = 111 then EA = (BX) + DISP

DISP follows 2nd byte of instruction (before data if required)

*except if mod = 00 and r/m = 110 then EA = disp-high: disp-low.

NOTE:
EA CALCULATION TIME IS 4 CLOCK CYCLES FOR ALL MODES, AND IS INCLUDED IN THE EXECUTION TIMES GIVEN WHENEVER APPROPRIATE.

SEGMENT OVERRIDE PREFIX

0	0	1	reg	1	1	0

reg is assigned according to the following:

reg	Segment Register
00	ES
01	CS
10	SS
11	DS

REG is assigned according to the following table:

16-Bit (w = 1)	8-Bit (w = 0)
000 AX	000 AL
001 CX	001 CL
010 DX	010 DL
011 BX	011 BL
100 SP	100 AH
101 BP	101 CH
110 SI	110 DH
111 DI	111 BH

The physical addresses of all operands addressed by the BP register are computed using the SS segment register. The physical addresses of the destination operands of the string primitive operations (those addressed by the DI register) are computed using the ES segment, which may not be overridden.

PRELIMINARY

iAPX 88/10
8-BIT HMOS MICROPROCESSOR
8088/8088-2

- 8-Bit Data Bus Interface
- 16-Bit Internal Architecture
- Direct Addressing Capability to 1 Mbyte of Memory
- Direct Software Compatibility with iAPX 86/10 (8086 CPU)
- 14-Word by 16-Bit Register Set with Symmetrical Operations
- 24 Operand Addressing Modes
- Byte, Word, and Block Operations
- 8-Bit and 16-Bit Signed and Unsigned Arithmetic in Binary or Decimal, Including Multiply and Divide
- Compatible with 8155-2, 8755A-2 and 8185-2 Multiplexed Peripherals
- Two Clock Rates:
  5 MHz for 8088
  8 MHz for 8088-2
- Available in EXPRESS
  - Standard Temperature Range
  - Extended Temperature Range

The Intel® iAPX 88/10 is a new generation, high performance microprocessor implemented in N-channel, depletion load, silicon gate technology (HMOS), and packaged in a 40-pin CerDIP package. The processor has attributes of both 8- and 16-bit microprocessors. It is directly compatible with iAPX 86/10 software and 8080/8085 hardware and peripherals.

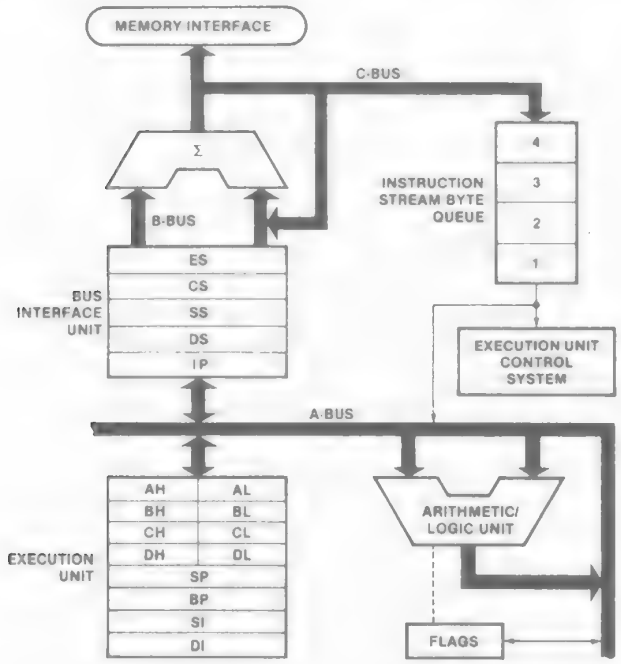


Figure 1. iAPX 88/10 CPU Functional Block Diagram

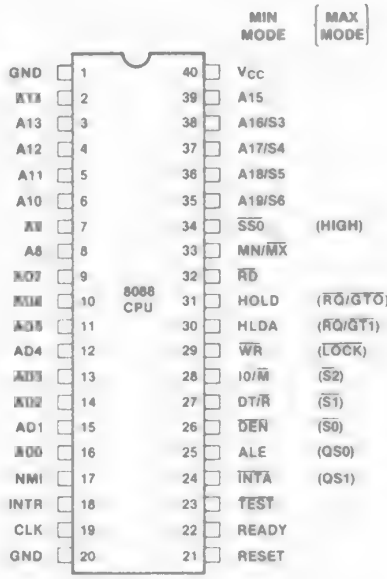


Figure 2. iAPX 88/10 Pin Configuration

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AFN-00826D

Table 1. Pin Description

The following pin function descriptions are for 8088 systems in either minimum or maximum mode. The "local bus" in these descriptions is the direct multiplexed bus interface connection to the 8088 (without regard to additional bus buffers).

Symbol	Pin No.	Type	Name and Function
AD7–AD0	9-16	I/O	**Address Data Bus:** These lines constitute the time multiplexed memory/IO address (T1) and data (T2, T3, Tw, and T4) bus. These lines are active HIGH and float to 3-state OFF during interrupt acknowledge and local bus "hold acknowledge".
A15–A8	2-8, 39	O	**Address Bus:** These lines provide address bits 8 through 15 for the entire bus cycle (T1–T4). These lines do not have to be latched by ALE to remain valid. A15–A8 are active HIGH and float to 3-state OFF during interrupt acknowledge and local bus "hold acknowledge".
A19/S6, A18/S5, A17/S4, A16/S3	34-38	O	**Address/Status:** During T1, these are the four most significant address lines for memory operations. During I/O operations, these lines are LOW. During memory and I/O operations, status information is available on these lines during T2, T3, Tw, and T4. S6 is always low. The status of the interrupt enable flag bit (S5) is updated at the beginning of each clock cycle. S4 and S3 are encoded as shown. This information indicates which segment register is presently being used for data accessing. These lines float to 3-state OFF during local bus "hold acknowledge".
$\overline{RD}$	32	O	**Read:** Read strobe indicates that the processor is performing a memory or I/O read cycle, depending on the state of the IO/$\overline{M}$ pin or S2. This signal is used to read devices which reside on the 8088 local bus. $\overline{RD}$ is active LOW during T2, T3 and Tw of any read cycle, and is guaranteed to remain HIGH in T2 until the 8088 local bus has floated. This signal floats to 3-state OFF in "hold acknowledge".
READY	22	I	**READY:** is the acknowledgement from the addressed memory or I/O device that it will complete the data transfer. The RDY signal from memory or I/O is synchronized by the 8284 clock generator to form READY. This signal is active HIGH. The 8088 READY input is not synchronized. Correct operation is not guaranteed if the set up and hold times are not met.
INTR	18	I	**Interrupt Request:** is a level triggered input which is sampled during the last clock cycle of each instruction to determine if the processor should enter into an interrupt acknowledge operation. A subroutine is vectored to via an interrupt vector lookup table located in system memory. It can be internally masked by software resetting the interrupt enable bit. INTR is internally synchronized. This signal is active HIGH.
$\overline{TEST}$	23	I	**$\overline{TEST}$:** Input is examined by the "wait for test" instruction. If the $\overline{TEST}$ input is LOW, execution continues, otherwise the processor waits in an "idle" state. This input is synchronized internally during each clock cycle on the leading edge of CLK.
NMI	17	I	**Non-Maskable Interrupt:** is an edge triggered input which causes a type 2 interrupt. A subroutine is vectored to via an interrupt vector lookup table located in system memory. NMI is not maskable internally by software. A transition from a LOW to HIGH initiates the interrupt at the end of the current instruction. This input is internally synchronized.

S4	S3	CHARACTERISTICS
0 (LOW)	0	Alternate Data
0	1	Stack
1 (HIGH)	0	Code or None
1	1	[illegible]
S6 is 0 (LOW)[1]		

Table 1. Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
RESET	21	I	**RESET:** causes the processor to immediately terminate its present activity. The signal must be active HIGH for at least four clock cycles. It restarts execution, as described in the instruction set description, when RESET returns LOW. RESET is internally synchronized.
CLK	19	I	**Clock:** provides the basic timing for the processor and bus controller. It is asymmetric with a 33% duty cycle to provide optimized internal timing.
V_{CC}	40		**V_{CC}:** is the +5V ±10% power supply pin.
GND	1, 20		**GND:** are the ground pins.
MN/$\overline{MX}$	33	I	**Minimum/Maximum:** indicates what mode the processor is to operate in. The two modes are discussed in the following sections.

The following pin function descriptions are for the 8088 minimum mode (i.e., MN/MX = V_{CC}). Only the pin functions which are unique to minimum mode are described; all other pin functions are as described above.

IO/$\overline{M}$	28	O	**Status Line:** is an inverted maximum mode $\overline{S2}$. It is used to distinguish a memory access from an I/O access. IO/$\overline{M}$ becomes valid in the T4 preceding a bus cycle and remains valid until the final T4 of the cycle (I/O=HIGH, M=LOW). IO/$\overline{M}$ floats to 3-state OFF in local bus "hold acknowledge".
$\overline{WR}$	29	O	**Write:** strobe indicates that the processor is performing a write memory or write I/O cycle, depending on the state of the IO/$\overline{M}$ signal. WR is active for T2, T3, and Tw of any write cycle. It is active LOW, and floats to 3-state OFF in local bus "hold acknowledge".
$\overline{INTA}$	24	O	**INTA:** is used as a read strobe for interrupt acknowledge cycles. It is active LOW during T2, T3, and Tw of each interrupt acknowledge cycle.
ALE	25	O	**Address Latch Enable:** is provided by the processor to latch the address into the 8282/8283 address latch. It is a HIGH pulse active during clock low of T1 of any bus cycle. Note that ALE is never floated.
DT/$\overline{R}$	27	O	**Data Transmit/Receive:** is needed in a minimum system that desires to use an 8286/8287 data bus transceiver. It is used to control the direction of data flow through the transceiver. Logically, DT/$\overline{R}$ is equivalent to $\overline{S1}$ in the maximum mode, and its timing is the same as for IO/$\overline{M}$ (T=HIGH, R=LOW). This signal floats to 3-state OFF in local "hold acknowledge".
$\overline{DEN}$	26	O	**Data Enable:** is provided as an output enable for the 8286/8287 in a minimum system which uses the transceiver. $\overline{DEN}$ is active LOW during each memory and I/O access, and for $\overline{INTA}$ cycles. For a read or $\overline{INTA}$ cycle, it is active from the middle of T2 until the middle of T4, while for a write cycle, it is active from the beginning of T2 until the middle of T4. $\overline{DEN}$ floats to 3-state OFF during local bus "hold acknowledge".
HOLD, HLDA	30,31	I, O	**HOLD:** indicates that another master is requesting a local bus "hold". To be acknowledged, HOLD must be active HIGH. The processor receiving the "hold" request will issue HLDA (HIGH) as an acknowledgement, in the middle of a T4 or TI clock cycle. Simultaneous with the issuance of HLDA the processor will float the local bus and control lines. After HOLD is detected as being LOW, the processor lowers HLDA, and when the processor needs to run another cycle, it will again drive the local bus and control lines. Hold is not an asynchronous input. External synchronization should be provided if the system cannot otherwise guarantee the set up time.
$\overline{SSO}$	34	O	**Status line:** is logically equivalent to $\overline{S0}$ in the maximum mode. The combination of $\overline{SSO}$, IO/$\overline{M}$ and DT/$\overline{R}$ allows the system to completely decode the current bus cycle status.

IO/$\overline{M}$	DT/$\overline{R}$	$\overline{SSO}$	CHARACTERISTICS
1 (HIGH)	0	0	Interrupt Acknowledge
	0	1	Read I/O port
	1	0	Write I/O port
			Halt
0 (LOW)	0	0	Code access
	0	1	Read memory
	1	0	Write memory
		1	Passive

Table 1. Pin Description (Continued)

The following pin function descriptions are for the 8088, 8228 system in maximum mode (i.e., MN/MX=GND.) Only the pin functions which are unique to maximum mode are described; all other pin functions are as described above.

Symbol	Pin No.	Type	Name and Function
$\overline{S2}$, $\overline{S1}$, $\overline{S0}$	26-28	O	**Status:** is active during clock high of T4, T1, and T2, and is returned to the passive state (1,1,1) during T3 or during Tw when READY is HIGH. This status is used by the 8288 bus controller to generate all memory and I/O access control signals. Any change by $\overline{S2}$, $\overline{S1}$, or $\overline{S0}$ during T4 is used to indicate the beginning of a bus cycle, and the return to the passive state in T3 or Tw is used to indicate the end of a bus cycle. These signals float to 3-state OFF during "hold acknowledge". During the first clock cycle after RESET becomes active, these signals are active HIGH. After this first clock, they float to 3-state OFF. $\overline{S2}$ $\overline{S1}$ $\overline{S0}$ CHARACTERISTICS 0 (LOW) 0 0 Interrupt Acknowledge 0 0 1 Read I/O port 0 1 0 Write I/O port 0 1 1 Halt 1 (HIGH) 0 0 Code access 1 0 1 Read memory 1 1 0 Write memory 1 1 1 Passive
$\overline{RQ}/\overline{GT0}$, $\overline{RQ}/\overline{GT1}$	30, 31	I/O	**Request/Grant:** pins are used by other local bus masters to force the processor to release the local bus at the end of the processor's current bus cycle. Each pin is bidirectional with $\overline{RQ}/\overline{GT0}$ having higher priority than $\overline{RQ}/\overline{GT1}$. $\overline{RQ}/\overline{GT}$ has an internal pull-up resistor, so may be left unconnected. The request/grant sequence is as follows (See Figure 8): 1. A pulse of one CLK wide from another local bus master indicates a local bus request ("hold") to the 8088 (pulse 1). 2. During a T4 or TI clock cycle, a pulse one clock wide from the 8088 to the requesting master (pulse 2), indicates that the 8088 has allowed the local bus to float and that it will enter the "hold acknowledge" state at the next CLK. The CPU's bus interface unit is disconnected logically from the local bus during "hold acknowledge". The same rules as for HOLD/HOLDA apply as for when the bus is released. 3. A pulse one CLK wide from the requesting master indicates to the 8088 (pulse 3) that the "hold" request is about to end and that the 8088 can reclaim the local bus at the next CLK. The CPU then enters T4. Each master-master exchange of the local bus is a sequence of three pulses. There must be one idle CLK cycle after each bus exchange. Pulses are active LOW. If the request is made while the CPU is performing a memory cycle, it will release the local bus during T4 of the cycle when all the following conditions are met: 1. Request occurs on or before T2. 2. Current cycle is not the low bit of a word. 3. Current cycle is not the first acknowledge of an interrupt acknowledge sequence. 4. A locked instruction is not currently executing. If the local bus is idle when the request is made the two possible events will follow: 1. Local bus will be released during the next clock. 2. A memory cycle will start within 3 clocks. Now the four rules for a currently active memory cycle apply with condition number 1 already satisfied.

Table 1. Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{\text{LOCK}}$	29	O	**$\overline{\text{LOCK}}$:** indicates that other system bus masters are not to gain control of the system bus while $\overline{\text{LOCK}}$ is active (LOW). The $\overline{\text{LOCK}}$ signal is activated by the "LOCK" prefix instruction and remains active until the completion of the next instruction. This signal is active LOW, and floats to 3-state off in "hold acknowledge".
QS1, QS0	24, 25	O	**Queue Status:** provide status to allow external tracking of the internal 8088 instruction queue. The queue status is valid during the CLK cycle after which the queue operation is performed. QS1 / QS0 / CHARACTERISTICS 0 (LOW) / 0 / No operation 0 / 1 / First byte of opcode from queue 1 (HIGH) / 0 / Empty the queue 1 / 1 / Subsequent byte from queue
—	34	O	Pin 34 is always high in the maximum mode.

FUNCTIONAL DESCRIPTION

Memory Organization

The processor provides a 20-bit address to memory which locates the byte being referenced. The memory is organized as a linear array of up to 1 million bytes, addressed as 00000(H) to FFFFF(H). The memory is logically divided into code, data, extra data, and stack segments of up to 64K bytes each, with each segment falling on 16-byte boundaries. (See Figure 3.)

All memory references are made relative to base addresses contained in high speed segment registers. The segment types were chosen based on the addressing needs of programs. The segment register to be selected is automatically chosen according to the rules of the following table. All information in one segment type share the same logical attributes (e.g. code or data). By structuring memory into relocatable areas of similar characteristics and by automatically selecting segment registers, programs are shorter, faster, and more structured.

Word (16-bit) operands can be located on even or odd address boundaries. For address and data operands, the least significant byte of the word is stored in the lower valued address location and the most significant byte in the next higher address location. The BIU will automatically execute two fetch or write cycles for 16-bit operands.

Certain locations in memory are reserved for specific CPU operations. (See Figure 4.) Locations from addresses FFFF0H through FFFFFH are reserved for operations including a jump to the initial system initialization routine. Following RESET, the CPU will always begin execution at location FFFF0H where the jump must be located. Locations 00000H through 003FFH are reserved for interrupt operations. Four-byte pointers consisting of a 16-bit segment address and a 16-bit offset address direct program flow to one of the 256 possible interrupt service routines. The pointer elements are assumed to have been stored at their respective places in reserved memory prior to the occurrence of interrupts.

Minimum and Maximum Modes

The requirements for supporting minimum and maximum 8088 systems are sufficiently different that they cannot be done efficiently with 40 uniquely defined pins. Consequently, the 8088 is equipped with a strap pin (MN/$\overline{MX}$) which defines the system configuration. The definition of a certain subset of the pins changes, dependent on the condition of the strap pin. When the MN/$\overline{MX}$ pin is strapped to GND, the 8088 defines pins 24 through 31 and 34 in maximum mode. When the MN/$\overline{MX}$ pin is strapped to V_{CC}, the 8088 generates bus control signals itself on pins 24 through 31 and 34.

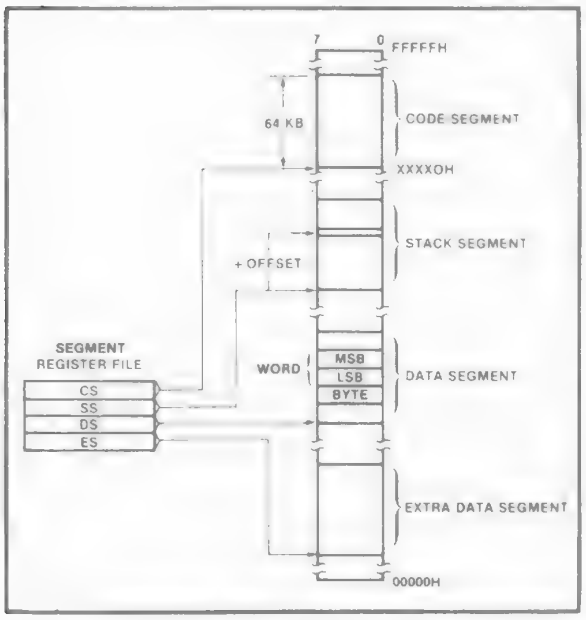

Figure 3. Memory Organization

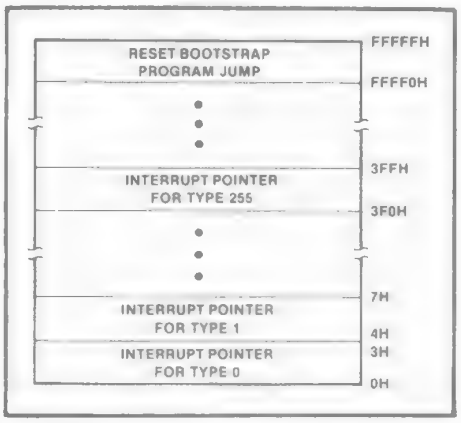

Figure 4. Reserved Memory Locations

Memory Reference Need	Segment Register Used	Segment Selection Rule
Instructions	CODE (CS)	Automatic with all instruction prefetch.
Stack	STACK (SS)	All stack pushes and pops. Memory references relative to BP base register except data references.
Local Data	DATA (DS)	Data references when: relative to stack, destination of string operation, or explicitly overridden.
External (Global) Data	EXTRA (ES)	Destination of string operations: Explicitly selected using a segment override.

The minimum mode 8088 can be used with either a multiplexed or demultiplexed bus. The multiplexed bus configuration is compatible with the MCS-85™ multiplexed bus peripherals (8155, 8156, 8355, 8755A, and 8185). This configuration (See Figure 5) provides the user with a minimum chip count system. This architecture provides the 8088 processing power in a highly integrated form.

The demultiplexed mode requires one latch (for 64K addressability) or two latches (for a full megabyte of addressing). A third latch can be used for buffering if the address bus loading requires it. An 8286 or 8287 transceiver can also be used if data bus buffering is required. (See Figure 6.) The 8088 provides $\overline{DEN}$ and DT/$\overline{R}$ to control the transceiver, and ALE to latch the addresses. This configuration of the minimum mode provides the standard demultiplexed bus structure with heavy bus buffering and relaxed bus timing requirements.

The maximum mode employs the 8288 bus controller. (See Figure 7.) The 8288 decodes status lines $\overline{S0}$, $\overline{S1}$, and $\overline{S2}$, and provides the system with all bus control signals. Moving the bus control to the 8288 provides better source and sink current capability to the control lines, and frees the 8088 pins for extended large system features. Hardware lock, queue status, and two request/grant interfaces are provided by the 8088 in maximum mode. These features allow co-processors in local bus and remote bus configurations.

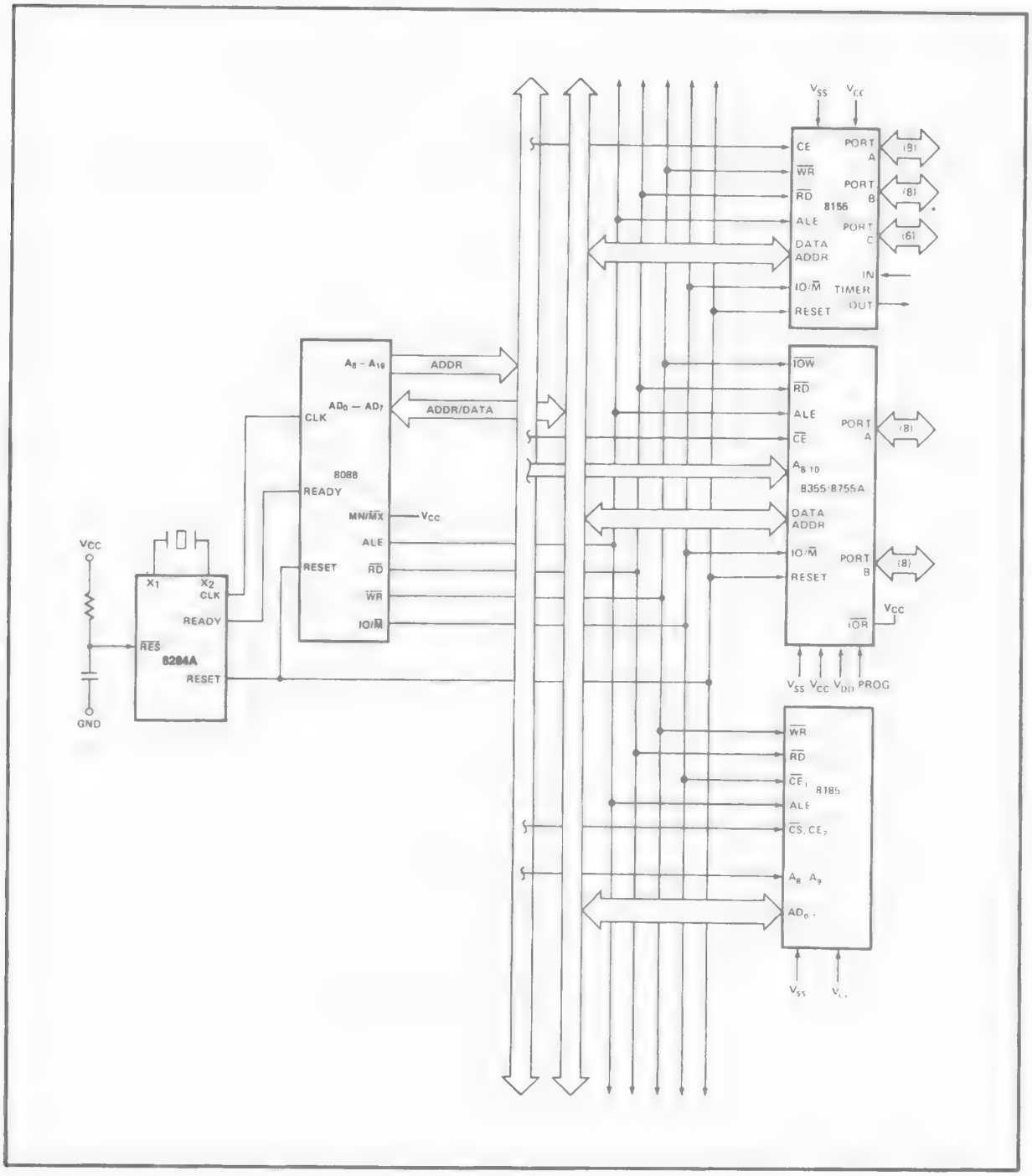

Figure 5. Multiplexed Bus Configuration

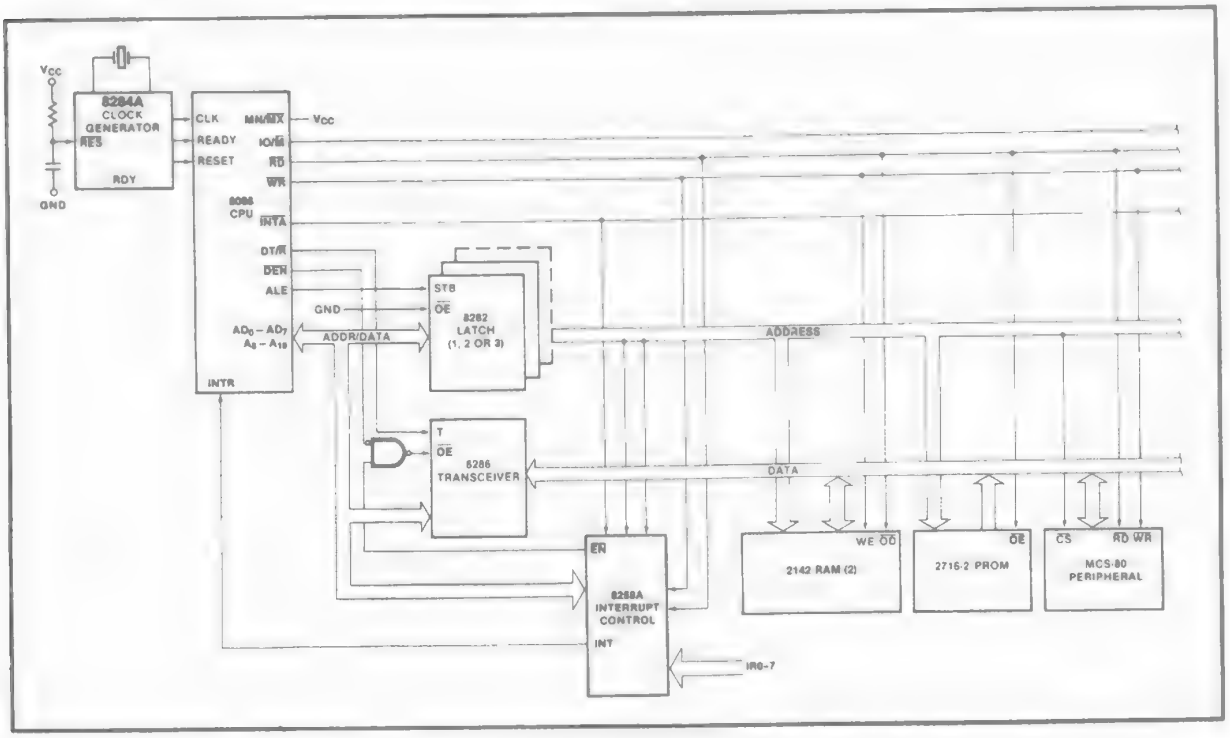

Figure 6. Demultiplexed Bus Configuration

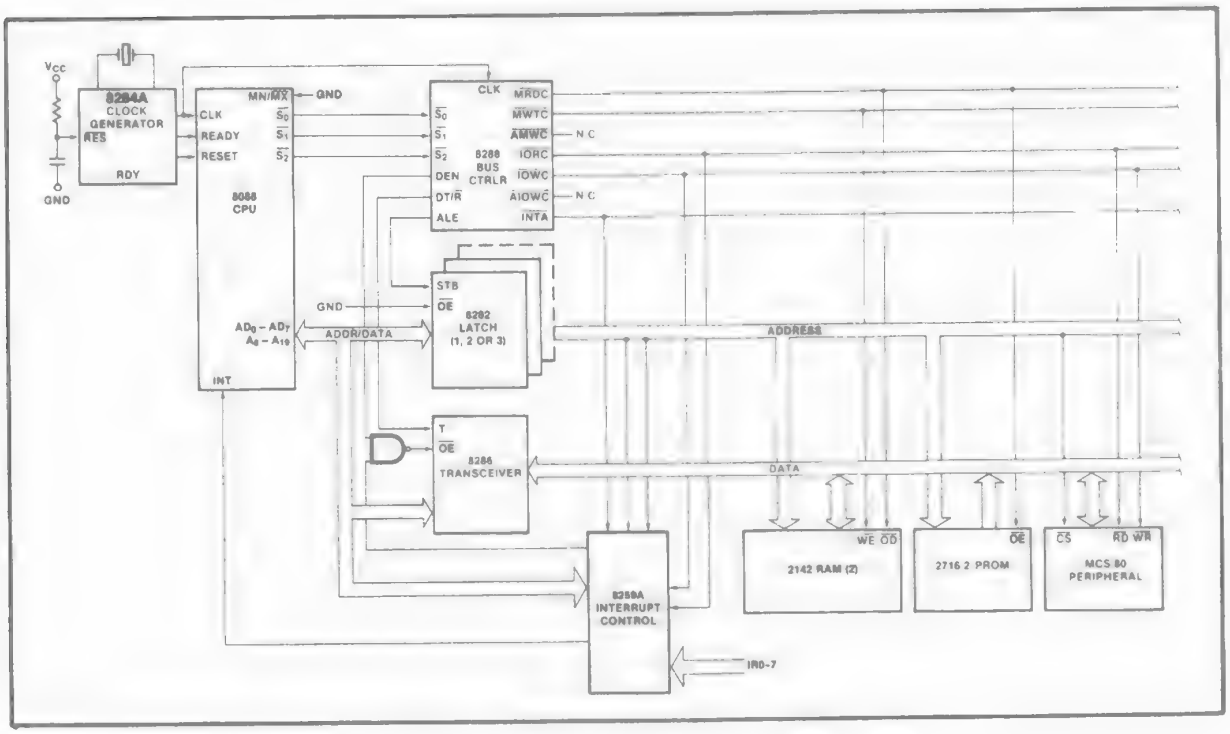

Figure 7. Fully Buffered System Using Bus Controller

Bus Operation

The 8088 address/data bus is broken into three parts — the lower eight address/data bits (AD0–AD7), the middle eight address bits (A8–A15), and the upper four address bits (A16–A19). The address/data bits and the highest four address bits are time multiplexed. This technique provides the most efficient use of pins on the processor, permitting the use of a standard 40 lead package. The middle eight address bits are not multiplexed, i.e. they remain valid throughout each bus cycle. In addition, the bus can be demultiplexed at the processor with a single address latch if a standard, non-multiplexed bus is desired for the system.

Each processor bus cycle consists of at least four CLK cycles. These are referred to as T1, T2, T3, and T4. (See Figure 8). The address is emitted from the processor during T1 and data transfer occurs on the bus during T3 and T4. T2 is used primarily for changing the direction of the bus during read operations. In the event that a "NOT READY" indication is given by the addressed device,

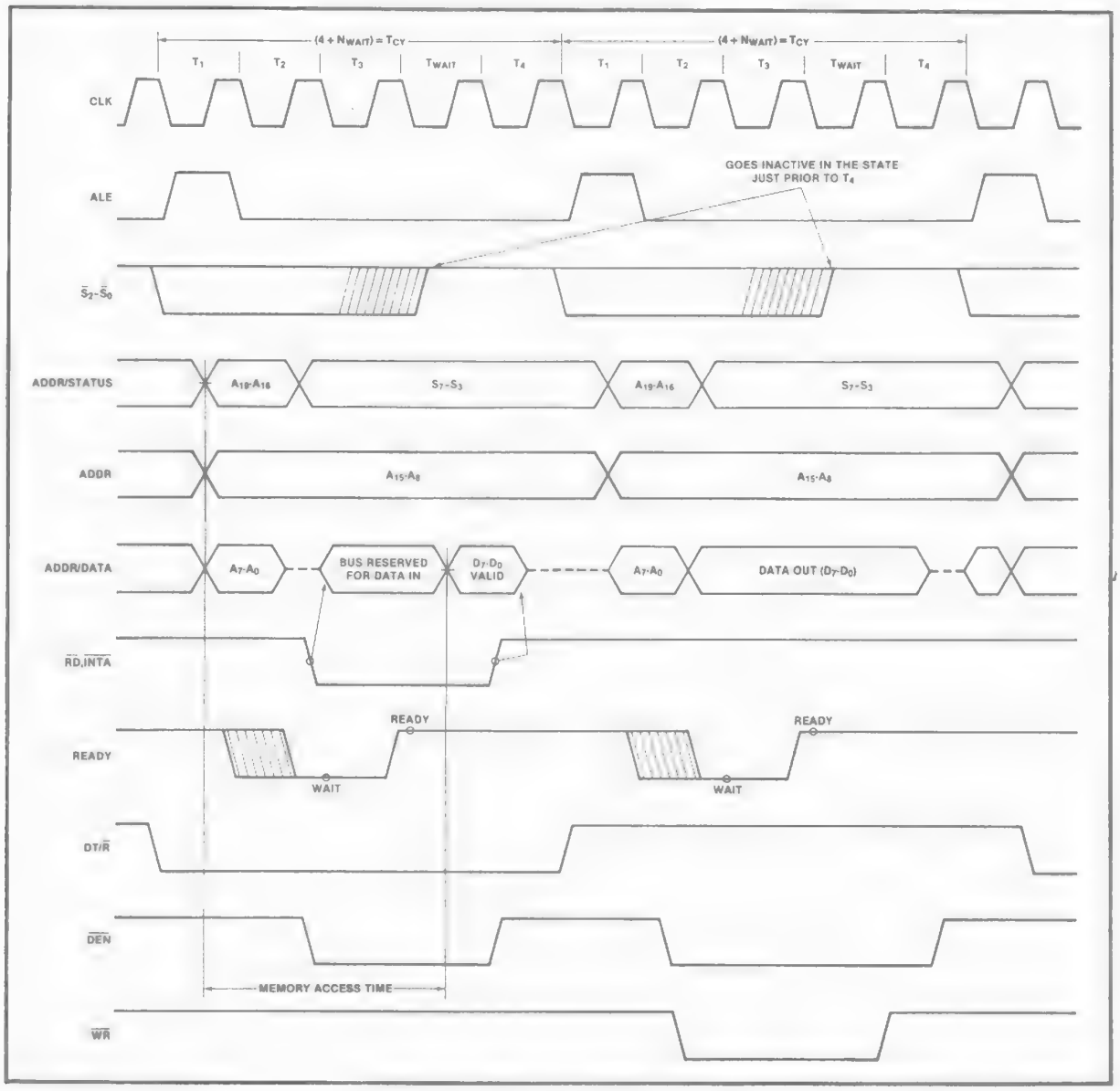

Figure 8. Basic System Timing

"wait" states (Tw) are inserted between T3 and T4. Each inserted "wait" state is of the same duration as a CLK cycle. Periods can occur between 8088 driven bus cycles. These are referred to as "idle" states (Ti), or inactive CLK cycles. The processor uses these cycles for internal housekeeping.

During T1 of any bus cycle, the ALE (address latch enable) signal is emitted (by either the processor or the 8288 bus controller, depending on the MN/$\overline{MX}$ strap). At the trailing edge of this pulse, a valid address and certain status information for the cycle may be latched.

Status bits $\overline{S0}$, $\overline{S1}$, and $\overline{S2}$ are used by the bus controller, in maximum mode, to identify the type of bus transaction according to the following table:

$\overline{S_2}$	$\overline{S_1}$	$\overline{S_0}$	CHARACTERISTICS
0 (LOW)	0	0	Interrupt Acknowledge
0	0	1	Read I/O
0	1	0	Write I/O
0	1	1	Halt
1 (HIGH)	0	0	Instruction Fetch
1	0	1	Read Data from Memory
1	1	0	Write Data to Memory
1	1	1	Passive (no bus cycle)

Status bits S3 through S6 are multiplexed with high order address bits and are therefore valid during T2 through T4. S3 and S4 indicate which segment register was used for this bus cycle in forming the address according to the following table:

S_4	S_3	CHARACTERISTICS
0 (LOW)	0	Alternate Data (extra segment)
0	1	Stack
1 (HIGH)	0	Code or None
1	1	Data

S5 is a reflection of the PSW interrupt enable bit. S6 is always equal to 0.

I/O Addressing

In the 8088, I/O operations can address up to a maximum of 64K I/O registers. The I/O address appears in the same format as the memory address on bus lines A15-A0. The address lines A19-A16 are zero in I/O operations. The variable I/O instructions, which use register DX as a pointer, have full address capability, while the direct I/O instructions directly address one or two of the 256 I/O byte locations in page 0 of the I/O address space. I/O ports are addressed in the same manner as memory locations.

Designers familiar with the 8085 or upgrading an 8085 design should note that the 8085 addresses I/O with an 8-bit address on both halves of the 16-bit address bus. The 8088 uses a full 16-bit address on its lower 16 address lines.

EXTERNAL INTERFACE

Processor Reset and Initialization

Processor initialization or start up is accomplished with activation (HIGH) of the RESET pin. The 8088 RESET is required to be HIGH for greater than four clock cycles. The 8088 will terminate operations on the high-going edge of RESET and will remain dormant as long as RESET is HIGH. The low-going transition of RESET triggers an internal reset sequence for approximately 7 clock cycles. After this interval the 8088 operates normally, beginning with the instruction in absolute location FFFF0H. (See Figure 4.) The RESET input is internally synchronized to the processor clock. At initialization, the HIGH to LOW transition of RESET must occur no sooner than 50 μs after power up, to allow complete initialization of the 8088.

If INTR is asserted sooner than nine clock cycles after the end of RESET, the processor may execute one instruction before responding to the interrupt.

All 3-state outputs float to 3-state OFF during RESET. Status is active in the idle state for the first clock after RESET becomes active and then floats to 3-state OFF.

Interrupt Operations

Interrupt operations fall into two classes: software or hardware initiated. The software initiated interrupts and software aspects of hardware interrupts are specified in the instruction set description in the iAPX 88 book or the iAPX 86,88 User's Manual. Hardware interrupts can be classified as nonmaskable or maskable.

Interrupts result in a transfer of control to a new program location. A 256 element table containing address pointers to the interrupt service program locations resides in absolute locations 0 through 3FFH (see Figure 4), which are reserved for this purpose. Each element in the table is 4 bytes in size and corresponds to an interrupt "type." An interrupting device supplies an 8-bit type number, during the interrupt acknowledge sequence, which is used to vector through the appropriate element to the new interrupt service program location.

Non-Maskable Interrupt (NMI)

The processor provides a single non-maskable interrupt (NMI) pin which has higher priority than the maskable interrupt request (INTR) pin. A typical use would be to activate a power failure routine. The NMI is edge-triggered on a LOW to HIGH transition. The activation of this pin causes a type 2 interrupt.

NMI is required to have a duration in the HIGH state of greater than two clock cycles, but is not required to be synchronized to the clock. Any higher going transition of NMI is latched on-chip and will be serviced at the end of the current instruction or between whole moves (2 bytes in the case of word moves) of a block type instruction. Worst case response to NMI would be for multiply, divide, and variable shift instructions. There is no specification on the occurrence of the low-going edge; it may occur

before, during, or after the servicing of NMI. Another high-going edge triggers another response if it occurs after the start of the NMI procedure. The signal must be free of logical spikes in general and be free of bounces on the low-going edge to avoid triggering extraneous responses.

Maskable Interrupt (INTR)

The 8088 provides a single interrupt request input (INTR) which can be masked internally by software with the resetting of the interrupt enable (IF) flag bit. The interrupt request signal is level triggered. It is internally synchronized during each clock cycle on the high-going edge of CLK. To be responded to, INTR must be present (HIGH) during the clock period preceding the end of the current instruction or the end of a whole move for a block type instruction. During interrupt response sequence, further interrupts are disabled. The enable bit is reset as part of the response to any interrupt (INTR, NMI, software interrupt, or single step), although the FLAGS register which is automatically pushed onto the stack reflects the state of the processor prior to the interrupt. Until the old FLAGS register is restored, the enable bit will be zero unless specifically set by an instruction.

During the response sequence (See Figure 9), the processor executes two successive (back to back) interrupt acknowledge cycles. The 8088 emits the LOCK signal (maximum mode only) from T2 of the first bus cycle until T2 of the second. A local bus "hold" request will not be honored until the end of the second bus cycle. In the second bus cycle, a byte is fetched from the external interrupt system (e.g., 8259A PIC) which identifies the source (type) of the interrupt. This byte is multiplied by four and used as a pointer into the interrupt vector lookup table. An INTR signal left HIGH will be continually responded to within the limitations of the enable bit and sample period. The interrupt return instruction includes a flags pop which returns the status of the original interrupt enable bit when it restores the flags.

HALT

When a software HALT instruction is executed, the processor indicates that it is entering the HALT state in one of two ways, depending upon which mode is strapped. In minimum mode, the processor issues ALE, delayed by one clock cycle, to allow the system to latch the halt status. Halt status is available on IO/$\overline{M}$, DT/$\overline{R}$, and $\overline{SSO}$. In maximum mode, the processor issues appropriate HALT status on $\overline{S2}$, $\overline{S1}$, and $\overline{S0}$, and the 8288 bus controller issues one ALE. The 8088 will not leave the HALT state when a local bus hold is entered while in HALT. In this case, the processor reissues the HALT indicator at the end of the local bus hold. An interrupt request or RESET will force the 8088 out of the HALT state.

Read/Modify/Write (Semaphore) Operations via LOCK

The LOCK status information is provided by the processor when consecutive bus cycles are required during the execution of an instruction. This allows the processor to perform read/modify/write operations on memory (via the "exchange register with memory" instruction), without another system bus master receiving intervening memory cycles. This is useful in multiprocessor system configurations to accomplish "test and set lock" operations. The $\overline{LOCK}$ signal is activated (LOW) in the clock cycle following decoding of the LOCK prefix instruction. It is deactivated at the end of the last bus cycle of the instruction following the LOCK prefix. While $\overline{LOCK}$ is active, a request on a $\overline{RQ}$/$\overline{GT}$ pin will be recorded, and then honored at the end of the LOCK.

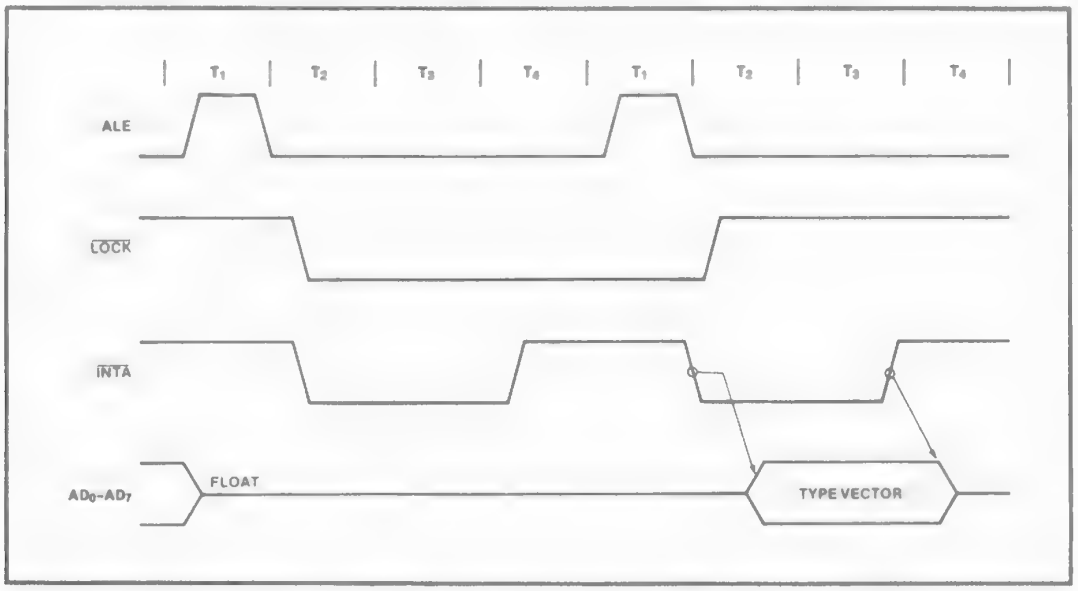

Figure 9. Interrupt Acknowledge Sequence

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External Synchronization via $\overline{TEST}$

As an alternative to interrupts, the 8088 provides a single software-testable input pin ($\overline{TEST}$). This input is utilized by executing a WAIT instruction. The single WAIT instruction is repeatedly executed until the $\overline{TEST}$ input goes active (LOW). The execution of WAIT does not consume bus cycles once the queue is full.

If a local bus request occurs during WAIT execution, the 8088 3-states all output drivers. If interrupts are enabled, the 8088 will recognize interrupts and process them. The WAIT instruction is then refetched, and reexecuted.

Basic System Timing

In minimum mode, the MN/$\overline{MX}$ pin is strapped to V_{CC} and the processor emits bus control signals compatible with the 8085 bus structure. In maximum mode, the MN/$\overline{MX}$ pin is strapped to GND and the processor emits coded status information which the 8288 bus controller uses to generate MULTIBUS compatible bus control signals.

System Timing — Minimum System

(See Figure 8.)

The read cycle begins in T1 with the assertion of the address latch enable (ALE) signal. The trailing (low going) edge of this signal is used to latch the address information, which is valid on the address/data bus (AD0–AD7) at this time, into the 8282/8283 latch. Address lines A8 through A15 do not need to be latched because they remain valid throughout the bus cycle. From T1 to T4 the IO/$\overline{M}$ signal indicates a memory or I/O operation. At T2 the address is removed from the address/data bus and the bus goes to a high impedance state. The read control signal is also asserted at T2. The read ($\overline{RD}$) signal causes the addressed device to enable its data bus drivers to the local bus. Some time later, valid data will be available on the bus and the addressed device will drive the READY line HIGH. When the processor returns the read signal to a HIGH level, the addressed device will again 3-state its bus drivers. If a transceiver (8286/8287) is required to buffer the 8088 local bus, signals DT/$\overline{R}$ and $\overline{DEN}$ are provided by the 8088.

A write cycle also begins with the assertion of ALE and the emission of the address. The IO/$\overline{M}$ signal is again asserted to indicate a memory or I/O write operation. In T2, immediately following the address emission, the processor emits the data to be written into the addressed location. This data remains valid until at least the middle of T4. During T2, T3, and T_W, the processor asserts the write control signal. The write ($\overline{WR}$) signal becomes active at the beginning of T2, as opposed to the read, which is delayed somewhat into T2 to provide time for the bus to float.

The basic difference between the interrupt acknowledge cycle and a read cycle is that the interrupt acknowledge ($\overline{INTA}$) signal is asserted in place of the read ($\overline{RD}$) signal and the address bus is floated. (See Figure 9.). In the second of two successive $\overline{INTA}$ cycles, a byte of information is read from the data bus, as supplied by the interrupt system logic (i.e. 8259A priority interrupt controller). This byte identifies the source (type) of the interrupt. It is multiplied by four and used as a pointer into the interrupt vector lookup table, as described earlier.

Bus Timing — Medium Complexity Systems

(See Figure 10.)

For medium complexity systems, the MN/$\overline{MX}$ pin is connected to GND and the 8288 bus controller is added to the system, as well as an 8282/8283 latch for latching the system address, and an 8286/8287 transceiver to allow for bus loading greater than the 8088 is capable of handling. Signals ALE, $\overline{DEN}$, and DT/$\overline{R}$ are generated by the 8288 instead of the processor in this configuration, although their timing remains relatively the same. The 8088 status outputs ($\overline{S2}$, $\overline{S1}$, and $\overline{S0}$) provide type of cycle information and become 8288 inputs. This bus cycle information specifies read (code, data, or I/O), write (data or I/O), interrupt acknowledge, or software halt. The 8288 thus issues control signals specifying memory read or write, I/O read or write, or interrupt acknowledge. The 8288 provides two types of write strobes, normal and advanced, to be applied as required. The normal write strobes have data valid at the leading edge of write. The advanced write strobes have the same timing as read strobes, and hence, data is not valid at the leading edge of write. The 8286/8287 transceiver receives the usual T and $\overline{OE}$ inputs from the 8288's DT/$\overline{R}$ and $\overline{DEN}$ outputs.

The pointer into the interrupt vector table, which is passed during the second $\overline{INTA}$ cycle, can derive from an 8259A located on either the local bus or the system bus. If the master 8289A priority interrupt controller is positioned on the local bus, a TTL gate is required to disable the 8286/8287 transceiver when reading from the master 8259A during the interrupt acknowledge sequence and software "poll".

The 8088 Compared to the 8086

The 8088 CPU is an 8-bit processor designed around the 8086 internal structure. Most internal functions of the 8088 are identical to the equivalent 8086 functions. The 8088 handles the external bus the same way the 8086 does with the distinction of handling only 8 bits at a time. Sixteen-bit operands are fetched or written in two consecutive bus cycles. Both processors will appear identical to the software engineer, with the exception of execution time. The internal register structure is identical and all instructions have the same end result. The differences between the 8088 and 8086 are outlined below. The engineer who is unfamiliar with the 8086 is referred to the iAPX 86, 88 User's Manual, Chapters 2 and 4, for function description and instruction set information. Internally, there are three differences between the 8088 and the 8086. All changes are related to the 8-bit bus interface.

- The queue length is 4 bytes in the 8088, whereas the 8086 queue contains 6 bytes, or three words. The queue was shortened to prevent overuse of the bus by the BIU when prefetching instructions. This was required because of the additional time necessary to fetch instructions 8 bits at a time.
- To further optimize the queue, the prefetching algorithm was changed. The 8088 BIU will fetch a new instruction to load into the queue each time there is a 1 byte hole (space available) in the queue. The 8086 waits until a 2-byte space is available.
- The internal execution time of the instruction set is affected by the 8-bit interface. All 16-bit fetches and writes from/to memory take an additional four clock cycles. The CPU is also limited by the speed of instruction fetches. This latter problem only occurs when a series of simple operations occur. When the more sophisticated instructions of the 8088 are being used, the queue has time to fill and the execution proceeds as fast as the execution unit will allow.

The 8088 and 8086 are completely software compatible by virture of their identical execution units. Software that is system dependent may not be completely transferable, but software that is not system dependent will operate equally as well on an 8088 or an 8086.

The hardware interface of the 8088 contains the major differences between the two CPUs. The pin assignments are nearly identical, however, with the following functional changes:

- A8–A15 — These pins are only address outputs on the 8088. These address lines are latched internally and remain valid throughout a bus cycle in a manner similar to the 8085 upper address lines.
- $\overline{BHE}$ has no meaning on the 8088 and has been eliminated.
- $\overline{SSO}$ provides the $\overline{SO}$ status information in the minimum mode. This output occurs on pin 34 in minimum mode only. DT/$\overline{R}$, IO/$\overline{M}$, and $\overline{SSO}$ provide the complete bus status in minimum mode.
- IO/$\overline{M}$ has been inverted to be compatible with the MCS-85 bus structure.
- ALE is delayed by one clock cycle in the minimum mode when entering HALT, to allow the status to be latched with ALE.

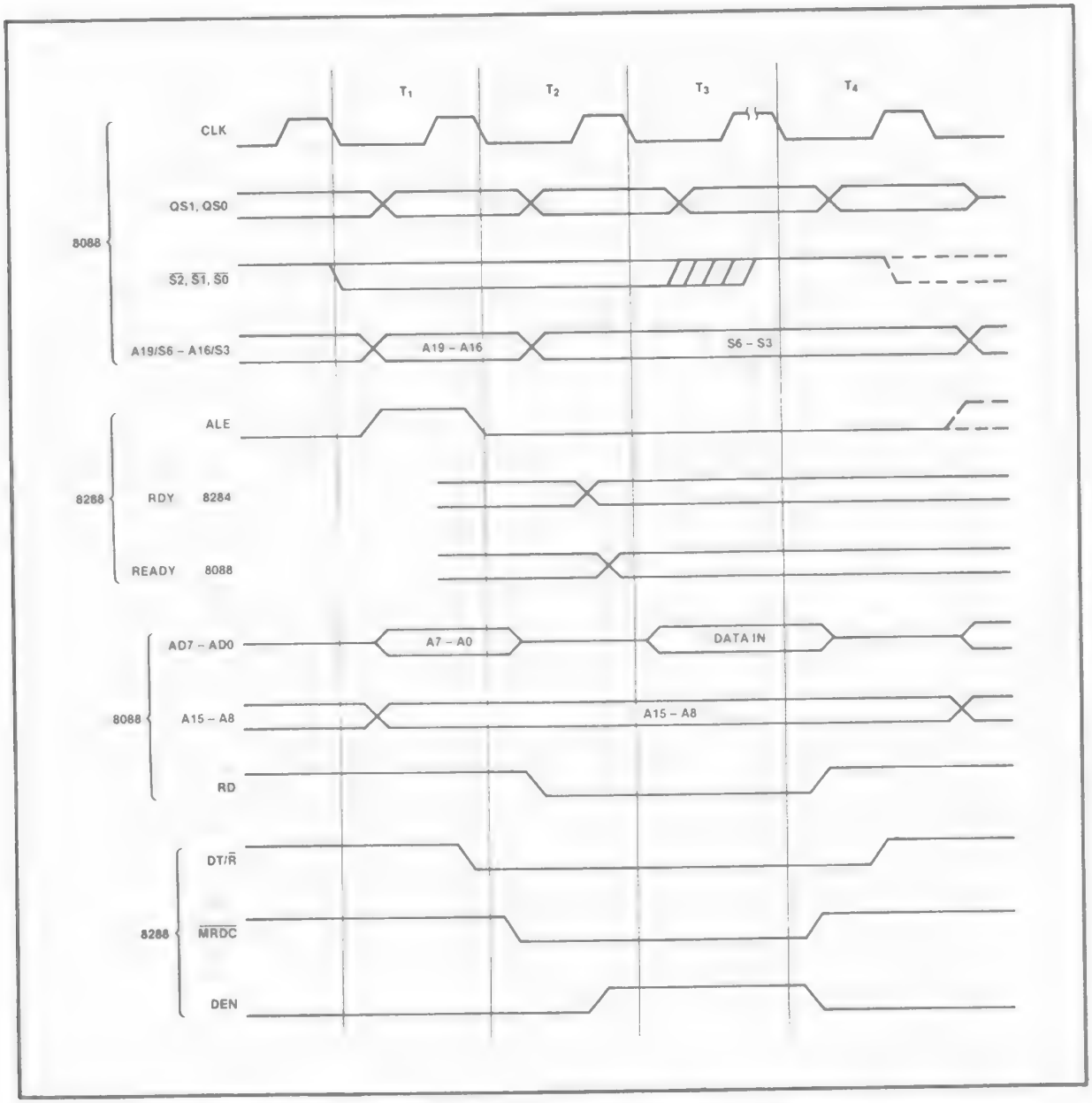


Figure 10. Medium Complexity System Timing

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias . . . . . 0°C to 70°C
Storage Temperature . . . . . – 65°C to + 150°C
Voltage on Any Pin with
Respect to Ground . . . . . – 1.0 to + 7V
Power Dissipation . . . . . 2.5 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS

(8088: T_A = 0°C to 70°C, V_{CC} = 5V ±10%) *
(8088-2: T_A = 0°C to 70°C, V_{CC} = 5V ±5%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	+0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC}+0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2.0 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400 μA
I_{CC}	Power Supply Current: 8088 8088-2 P8088		340 350 250	mA	T_A = 25°C
I_{LI}	Input Leakage Current		±10	μA	0V ≤ V_{IN} ≤ V_{CC}
I_{LO}	Output Leakage Current		±10	μA	0.45V ≤ V_{OUT} ≤ V_{CC}
V_{CL}	Clock Input Low Voltage	−0.5	+0.6	V	
V_{CH}	Clock Input High Voltage	3.9	V_{CC}+1.0	V	
C_{IN}	Capacitance if Input Buffer (All input except AD_0-AD_7, RQ/GT		15	pF	fc = 1 MHz
C_{IO}	Capacitance of I/O Buffer (AD_0-AD_7, RQ/GT		15	pF	fc = 1 MHz

*Note: For Extended Temperature EXPRESS V_{CC} = 5V ± 5%

A.C. CHARACTERISTICS (8088: T_A = 0°C to 70°C, V_{CC} = 5V ±10%)* (8088-2: T_A = 0°C to 70°C, V_{CC} = 5V ±5%)

MINIMUM COMPLEXITY SYSTEM TIMING REQUIREMENTS

		8088		8088-2			
Symbol	Parameter	Min.	Max.	Min.	Max.	Units	Test Conditions
TCLCL	CLK Cycle Period	200	500	125	500	ns	
TCLCH	CLK Low Time	118		68		ns	
TCHCL	CLK High Time	62		44		ns	
TCH1CH2	CLK Rise Time		10		10	ns	From 1.0V to 3.5V
TCL2CL1	CLK Fall Time		10		10	ns	From 3.5V to 1.0V
TDVCL	Data in Setup Time	30		20		ns	
TCLDX	Data in Hold Time	10		10		ns	
TR1VCL	RDY Setup Time into 8284 (See Notes 1, 2)	35		35		ns	
TCLR1X	RDY Hold Time into 8284 (See Notes 1, 2)	0		0		ns	
TRYHCH	READY Setup Time into 8088	118		68		ns	
TCHRYX	READY Hold Time into 8088	30		20		ns	
TRYLCL	READY Inactive to CLK (See Note 3)	−8		−8		ns	
THVCH	HOLD Setup Time	35		20		ns	
TINVCH	INTR, NMI, $\overline{TEST}$ Setup Time (See Note 2)	30		15		ns	
TILIH	Input Rise Time (Except CLK)		20		20	ns	From 0.8V to 2.0V
TIHIL	Input Fall Time (Except CLK)		12		12	ns	From 2.0V to 0.8V

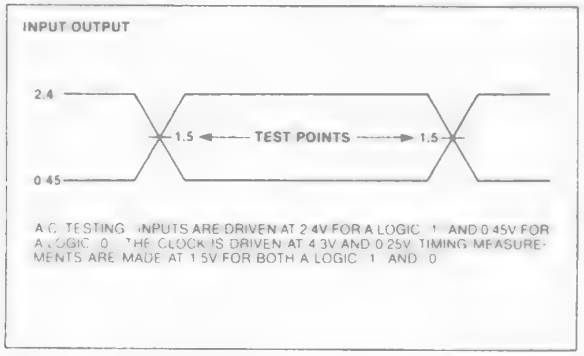
*Note: For Extended Temperature EXPRESS V_{CC} = 5V ± 5%

A.C. CHARACTERISTICS (Continued)

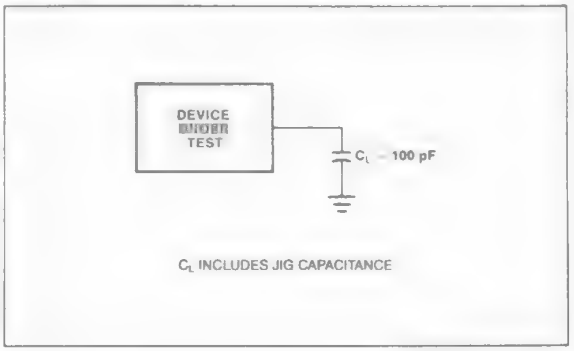
TIMING RESPONSES

Symbol	Parameter	8088 Min.	8088 Max.	8088-2 Min.	8088-2 Max.	Units	Test Conditions
TCLAV	Address Valid Delay	10	110	10	60	ns	C_L = 20-100 pF for all 8088 Outputs in addition to internal loads
TCLAX	Address Hold Time	10		10		ns	
TCLAZ	Address Float Delay	TCLAX	80	TCLAX	50	ns	
TLHLL	ALE Width	TCLCH−20		TCLCH−10		ns	
TCLLH	ALE Active Delay		80		50	ns	
TCHLL	ALE Inactive Delay		85		55	ns	
TLLAX	Address Hold Time to ALE Inactive	TCHCL−10		TCHCL−10		ns	
TCLDV	Data Valid Delay	10	110	10	60	ns	
TCHDX	Data Hold Time	10		10		ns	
TWHDX	Data Hold Time After $\overline{WR}$	TCLCH−30		TCLCH−30		ns	
TCVCTV	Control Active Delay 1	10	110	10	70	ns	
TCHCTV	Control Active Delay 2	10	110	10	60	ns	
TCVCTX	Control Inactive Delay	10	110	10	70	ns	
TAZRL	Address Float to READ Active	0		0		ns	
TCLRL	$\overline{RD}$ Active Delay	10	165	10	100	ns	
TCLRH	$\overline{RD}$ Inactive Delay	10	150	10	80	ns	
TRHAV	$\overline{RD}$ Inactive to Next Address Active	TCLCL−45		TCLCL−40		ns	
TCLHAV	HLDA Valid Delay	10	160	10	100	ns	
TRLRH	$\overline{RD}$ Width	2TCLCL−75		2TCLCL−50		ns	
TWLWH	$\overline{WR}$ Width	2TCLCL−60		2TCLCL−40		ns	
TAVAL	Address Valid to ALE Low	TCLCH−60		TCLCH−40		ns	
TOLOH	Output Rise Time		20		20	ns	From 0.8V to 2.0V
TOHOL	Output Fall Time		12		12	ns	From 2.0V to 0.8V

A.C. TESTING INPUT, OUTPUT WAVEFORM

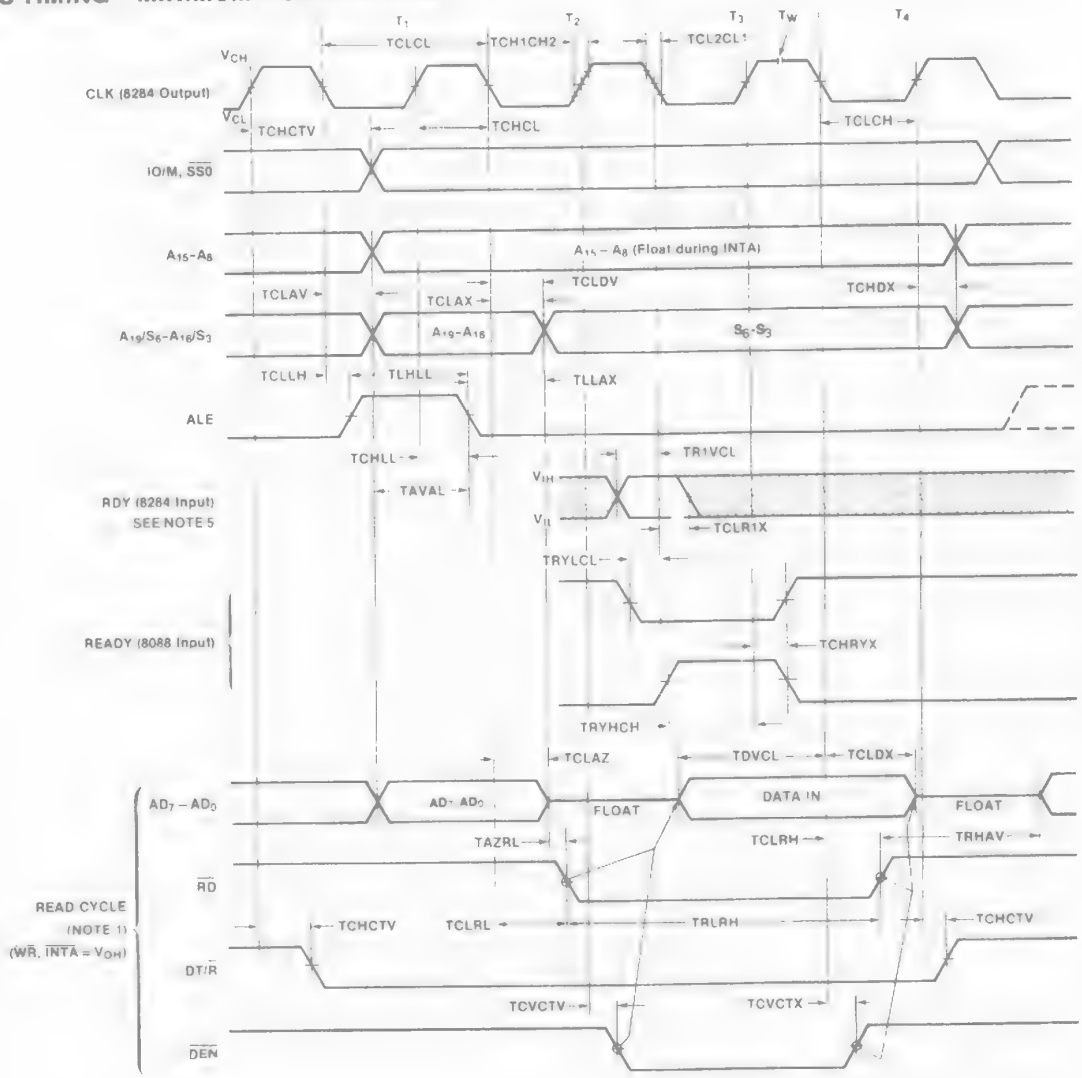


A.C. TESTING LOAD CIRCUIT



WAVEFORMS

BUS TIMING—MINIMUM MODE SYSTEM



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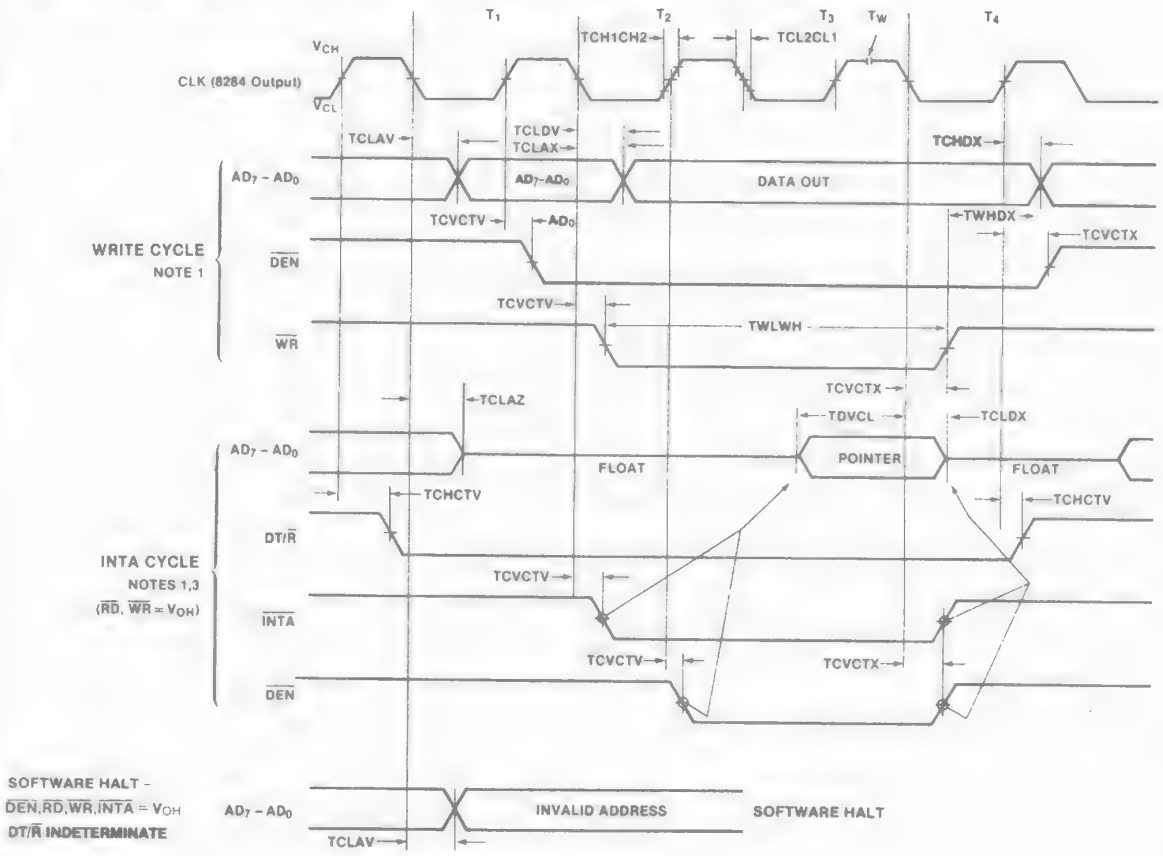
WAVEFORMS (Continued)

BUS TIMING—MINIMUM MODE SYSTEM (Continued)



NOTES:
1. ALL SIGNALS SWITCH BETWEEN V_{OH} AND V_{OL} UNLESS OTHERWISE SPECIFIED.
2. RDY IS SAMPLED NEAR THE END OF T_2, T_3, T_W TO DETERMINE IF T_W MACHINES STATES ARE TO BE INSERTED.
3. TWO INTA CYCLES RUN BACK-TO-BACK. THE 8088 LOCAL ADDR/DATA BUS IS FLOATING DURING BOTH INTA CYCLES. CONTROL SIGNALS ARE SHOWN FOR THE SECOND INTA CYCLE.
4. SIGNALS AT 8284 ARE SHOWN FOR REFERENCE ONLY.
5. ALL TIMING MEASUREMENTS ARE MADE AT 1.5V UNLESS OTHERWISE NOTED.

A.C. CHARACTERISTICS

MAX MODE SYSTEM (USING 8288 BUS CONTROLLER)

TIMING REQUIREMENTS

		8088		8088-2			
Symbol	**Parameter**	**Min.**	**Max.**	**Min.**	**Max.**	**Units**	**Test Conditions**
TCLCL	CLK Cycle Period	200	500	125	500	ns	
TCLCH	CLK Low Time	118		68		ns	
TCHCL	CLK High Time	69		44		ns	
TCH1CH2	CLK Rise Time		10		10	ns	From 1.0V to 3.5V
TCL2CL1	CLK Fall Time		10		10	ns	From 3.5V to 1.0V
TDVCL	Data In Setup Time	30		20		ns	
TCLDX	Data In Hold Time	10		10		ns	
TR1VCL	RDY Setup Time into 8284 (See Notes 1, 2)	35		35		ns	
TCLR1X	RDY Hold Time into 8284 (See Notes 1, 2)	0		0		ns	
TRYHCH	READY Setup Time into 8088	118		68		ns	
TCHRYX	READY Hold Time into 8088	30		20		ns	
TRYLCL	READY Inactive to CLK (See Note 4)	−8		−8		ns	
TINVCH	Setup Time for Recognition (INTR, NMI, TEST) (See Note 2)	30		15		ns	
TGVCH	RQ/GT Setup Time	30		15		ns	
TCHGX	RQ Hold Time into 8086	40		30		ns	
TILIH	Input Rise Time (Except CLK)		20		20	ns	From 0.8V to 2.0V
TIHIL	Input Fall Time (Except CLK)		12		12	ns	From 2.0V to 0.8V

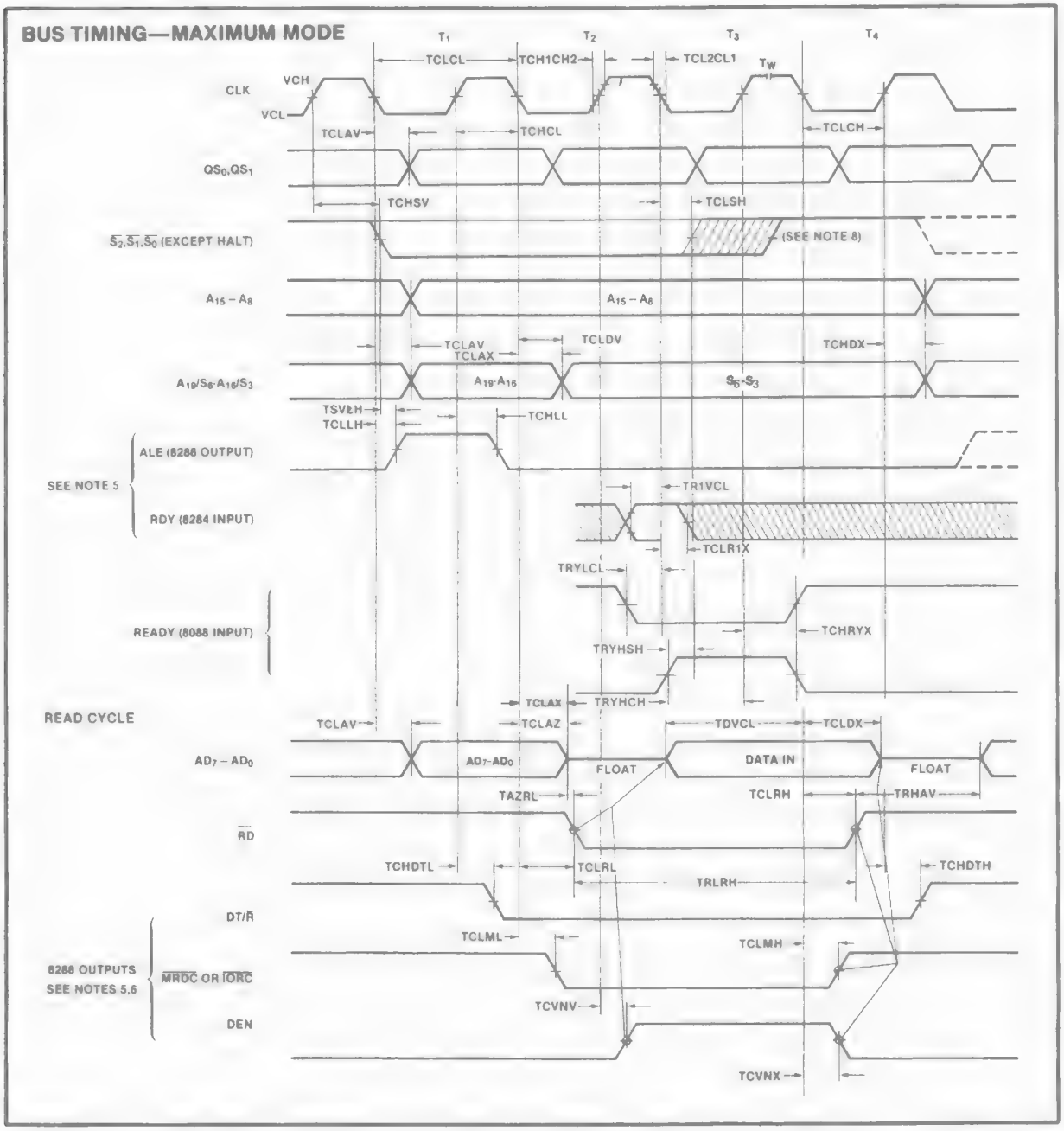
NOTES:
1. Signal at 8284 or 8288 shown for reference only.
2. Setup requirement for asynchronous signal only to guarantee recognition at next CLK.
3. Applies only to T2 state (8 ns into T3 state).
4. Applies only to T2 state (8 ns into T3 state).

A.C. CHARACTERISTICS

TIMING RESPONSES

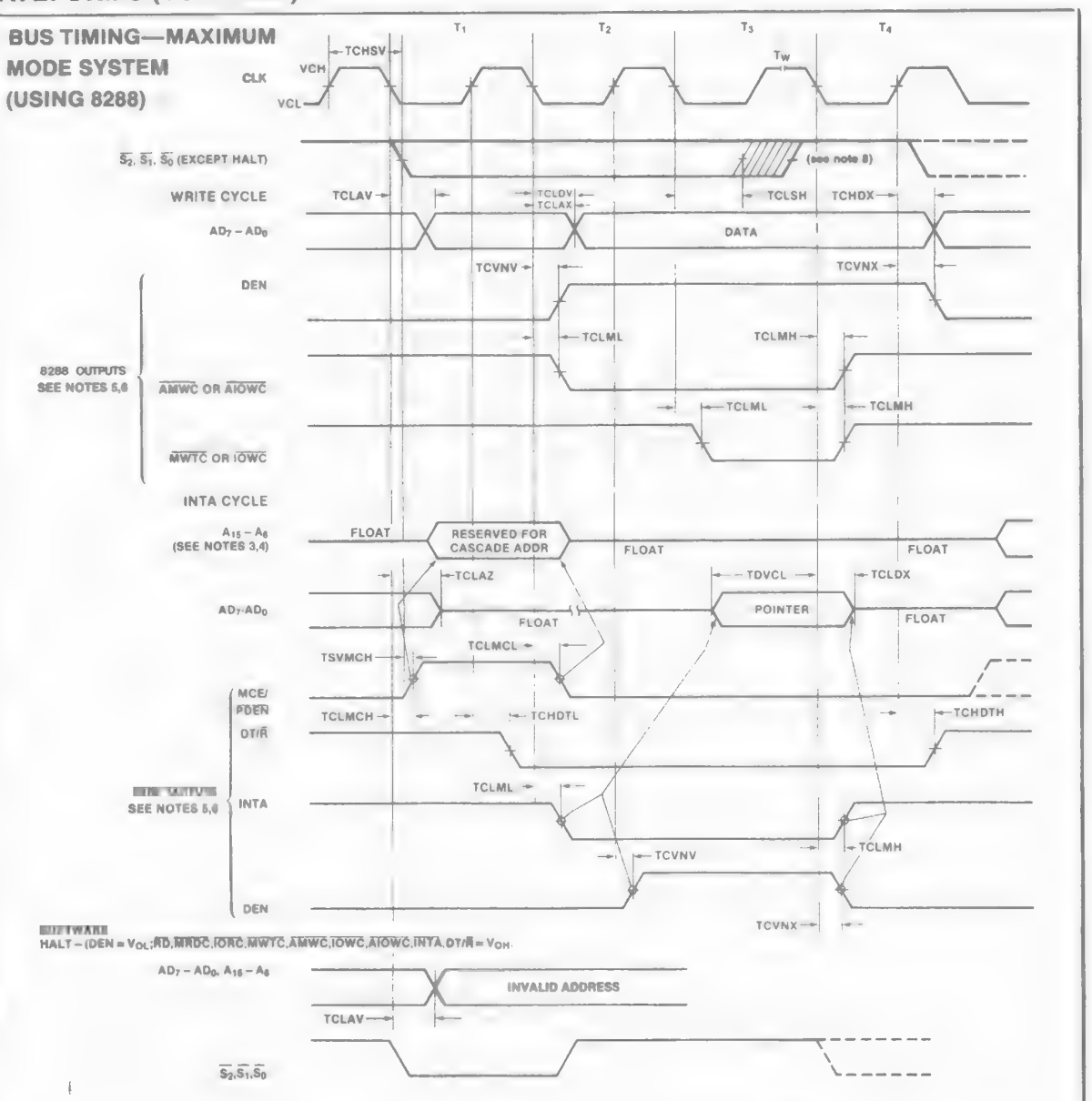
Symbol	Parameter	8088 Min.	8088 Max.	8088-2 Min.	8088-2 Max.	Units	Test Conditions
TCLML	Command Active Delay (See Note 1)	10	35	10	35	ns	
TCLMH	Command Inactive Delay (See Note 1)	10	35	10	35	ns	
TRYHSH	READY Active to Status Passive (See Note 3)		110		65	ns	
TCHSV	Status Active Delay	10	110	10	60	ns	
TCLSH	Status Inactive Delay	10	130	10	70	ns	
TCLAV	Address Valid Delay	10	110	10	60	ns	
TCLAX	Address Hold Time	10		10		ns	C_L = 20-100 pF for all 8088 Outputs in addition to internal loads
TCLAZ	Address Float Delay	TCLAX	80	TCLAX	50	ns	
TSVLH	Status Valid to ALE High (See Note 1)		15		15	ns	
TSVMCH	Status Valid to MCE High (See Note 1)		15		15	ns	
TCLLH	CLK Low to ALE Valid (See Note 1)		15		15	ns	
TCLMCH	CLK Low to MCE High (See Note 1)		15		15	ns	
TCHLL	ALE Inactive Delay (See Note 1)		15		15	ns	
TCLMCL	MCE Inactive Delay (See Note 1)		15		15	ns	
TCLDV	Data Valid Delay	10	110	10	60	ns	
TCHDX	Data Hold Time	10		10		ns	
TCVNV	Control Active Delay (See Note 1)	5	45	5	45	ns	
TCVNX	Control Inactive Delay (See Note 1)	10	45	10	45	ns	
TAZRL	Address Float to Read Active	0		0		ns	
TCLRL	RD Active Delay	10	165	10	100	ns	
TCLRH	RD Inactive Delay	10	150	10	80	ns	
TRHAV	RD Inactive to Next Address Active	TCLCL−45		TCLCL−40		ns	
TCHDTL	Direction Control Active Delay (See Note 1)		50		50	ns	
TCHDTH	Direction Control Inactive Delay (See Note 1)		30		30	ns	
TCLGL	GT Active Delay		85		50	ns	
TCLGH	GT Inactive Delay		85		50	ns	
TRLRH	RD Width	2TCLCL−75		2TCLCL−50		ns	
TOLOH	Output Rise Time		20		20	ns	From 0.8V to 2.0V
TOHOL	Output Fall Time		12		12	ns	From 2.0V to 0.8V

WAVEFORMS


BUS TIMING—MAXIMUM MODE
T1
T2
T3
T4
TCLCL
TCH1CH2
TCL2CL1
TW
CLK
VCH
VCL
TCLAV
TCHCL
TCLCH
QS0,QS1
TCHSV
TCLSH
S̄2,S̄1,S̄0 (EXCEPT HALT)
(SEE NOTE 8)
A15 – A8
TCLAV
TCLAX
TCLDV
TCHDX
A19/S6-A16/S3
A19-A16
S6-S3
TSVLH
TCLLH
TCHLL
ALE (8288 OUTPUT)
SEE NOTE 5
RDY (8284 INPUT)
TR1VCL
TCLR1X
TRYLCL
READY (8088 INPUT)
TCHRYX
TRYHSH
TCLAX
TRYHCH
READ CYCLE
TCLAV
TCLAZ
TDVCL
TCLDX
AD7 – AD0
AD7-AD0
FLOAT
DATA IN
FLOAT
TAZRL
TCLRH
TRHAV
RD
TCHDTL
TCLRL
TRLRH
TCHDTH
DT/R̄
TCLML
TCLMH
8288 OUTPUTS
SEE NOTES 5,6
MRDC OR IORC
TCVNV
DEN
TCVNX

WAVEFORMS (Continued)

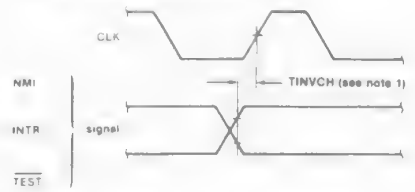
BUS TIMING—MAXIMUM MODE SYSTEM (USING 8288)



NOTES:
1. ALL SIGNALS SWITCH BETWEEN V_{OH} AND V_{OL} UNLESS OTHERWISE SPECIFIED.
2. RDY IS SAMPLED NEAR THE END OF T_2, T_3, T_W TO DETERMINE IF T_W MACHINES STATES ARE TO BE INSERTED.
3. CASCADE ADDRESS IS VALID BETWEEN FIRST AND SECOND INTA CYCLES.
4. TWO INTA CYCLES RUN BACK-TO-BACK. THE 8088 LOCAL ADDR/DATA BUS IS FLOATING DURING BOTH INTA CYCLES. CONTROL FOR POINTER ADDRESS IS SHOWN FOR SECOND INTA CYCLE.
5. SIGNALS AT 8284 OR 8288 ARE SHOWN FOR REFERENCE ONLY.
6. THE ISSUANCE OF THE 8288 COMMAND AND CONTROL SIGNALS (MRDC, MWTC, AMWC, IORC, IOWC, AIOWC, INTA AND DEN) LAGS THE ACTIVE HIGH 8288 CEN.
7. ALL TIMING MEASUREMENTS ARE MADE AT 1.5V UNLESS OTHERWISE NOTED.
8. STATUS INACTIVE IN STATE JUST PRIOR TO T_4.

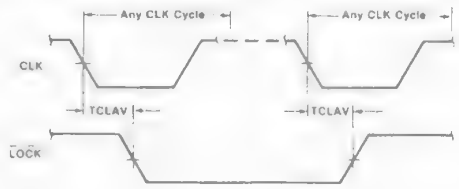
WAVEFORMS (Continued)

ASYNCHRONOUS SIGNAL RECOGNITION

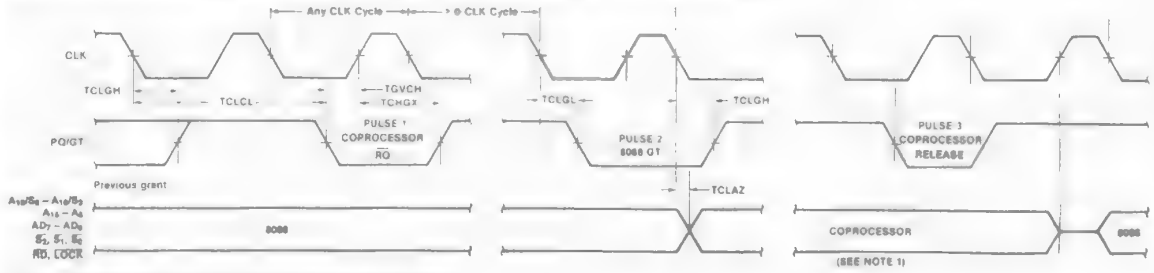


NOTE: 1. SETUP REQUIREMENTS FOR ASYNCHRONOUS SIGNALS ONLY TO GUARANTEE RECOGNITION AT NEXT CLK

BUS LOCK SIGNAL TIMING (MAXIMUM MODE ONLY)

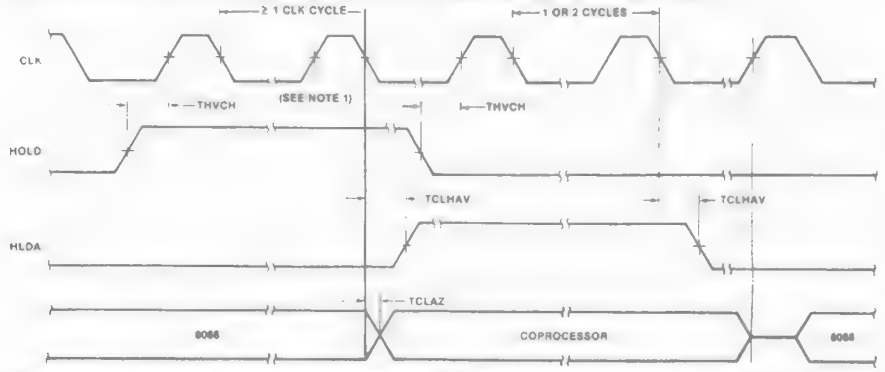


REQUEST/GRANT SEQUENCE TIMING (MAXIMUM MODE ONLY)



NOTE: 1. THE COPROCESSOR MAY NOT DRIVE THE BUSSES OUTSIDE THE REGION SHOWN WITHOUT RISKING CONTENTION

HOLD/HOLD ACKNOWLEDGE TIMING (MINIMUM MODE ONLY)



iAPX 86/10, 88/10
INSTRUCTION SET SUMMARY

DATA TRANSFER

MOV Move	76543210	76543210	76543210	76543210
Register/memory to/from register	100010dw	mod reg r/m		
Immediate to register/memory	1100011w	mod 000 r/m	data	data if w=1
Immediate to register	1011wreg	data	data if w=1	
Memory to accumulator	1010000w	addr-low	addr-high	
Accumulator to memory	1010001w	addr-low	addr-high	
Register/memory to segment register	10001110	mod 0reg r/m		
Segment register to register/memory	10001100	mod 0reg r/m		

PUSH Push	
Register/memory	11111111 mod 110 r/m
Register	01010reg
Segment register	000reg110

POP Pop	
Register/memory	10001111 mod 000 r/m
Register	01011reg
Segment register	000reg111

XCHG Exchange	
Register/memory with register	1000011w mod reg r/m
Register with accumulator	10010reg

IN Input from	
Fixed port	1110010w port
Variable port	1110110w

OUT Output to	
Fixed port	1110011w port
Variable port	1110111w
XLAT Translate byte to AL	11010111
LEA Load EA to register	10001101 mod reg r/m
LDS Load pointer to DS	11000101 mod reg r/m
LES Load pointer to ES	11000100 mod reg r/m
LAHF Load AH with flags	10011111
SAHF Store AH into flags	10011110
PUSHF Push flags	10011100
POPF Pop flags	10011101

ARITHMETIC

ADD Add				
Reg./memory with register to either	000000dw	mod reg r/m		
Immediate to register/memory	100000sw	mod 000 r/m	data	data if s:w=01
Immediate to accumulator	0000010w	data	data if w=1	

ADC Add with carry				
Reg./memory with register to either	000100dw	mod reg r/m		
Immediate to register/memory	100000sw	mod 010 r/m	data	data if s:w=01
Immediate to accumulator	0001010w	data	data if w=1	

INC Increment	
Register/memory	1111111w mod 000 r/m
Register	01000reg
AAA ASCII adjust for add	00110111
DAA Decimal adjust for add	00100111

SUB Subtract				
Reg./memory and register to either	001010dw	mod reg r/m		
Immediate from register/memory	100000sw	mod 101 r/m	data	data if s:w=01
Immediate from accumulator	0010110w	data	data if w=1	

SBB Subtract with borrow				
Reg./memory and register to either	000110dw	mod reg r/m		
Immediate from register/memory	100000sw	mod 011 r/m	data	data if s:w=01
Immediate from accumulator	0001110w	data	data if w=1	

DEC Decrement		
Register/memory	1111111w	mod 001 r/m
Register	01001reg	
NEG Change sign	1111011w	mod 011 r/m

CMP Compare				
Register/memory and register	0011101w	mod reg r/m		
Immediate with register/memory	100000sw	mod 111 r/m	data	data if s:w=01
Immediate with accumulator	0011110w	data	data if w=1	
AAS ASCII adjust for subtract	00111111			
DAS Decimal adjust for subtract	00101111			
MUL Multiply, unsigned	1111011w	mod 100 r/m		
IMUL Integer multiply, signed	1111011w	mod 101 r/m		
AAM ASCII adjust for multiply	11010100	00001010		
DIV Divide, unsigned	1111011w	mod 110 r/m		
IDIV Integer divide, signed	1111011w	mod 111 r/m		
AAD ASCII adjust for divide	11010101	00001010		
CBW Convert byte to word	10011000			
CWD Convert word to double word	10011001			

LOGIC

NOT Invert	1111011w	mod 010 r/m		
SHL/SAL Shift logical/arithmetic left	110100vw	mod 100 r/m		
SHR Shift logical right	110100vw	mod 101 r/m		
SAR Shift arithmetic right	110100vw	mod 111 r/m		
ROL Rotate left	110100vw	mod 000 r/m		
ROR Rotate right	110100vw	mod 001 r/m		
RCL Rotate through carry flag left	110100vw	mod 010 r/m		
RCR Rotate through carry right	110100vw	mod 011 r/m		

AND And				
Reg./memory and register to either	001000dw	mod reg r/m		
Immediate to register/memory	1000000w	mod 100 r/m	data	data if w=1
Immediate to accumulator	0010010w	data	data if w=1	

TEST And function to flags, no result				
Register/memory and register	1000010w	mod reg r/m		
Immediate data and register/memory	1111011w	mod 000 r/m	data	data if w=1
Immediate data and accumulator	1010100w	data	data if w=1	

OR Or				
Reg./memory and register to either	000010dw	mod reg r/m		
Immediate to register/memory	1000000w	mod 001 r/m	data	data if w=1
Immediate to accumulator	0000110w	data	data if w=1	

XOR Exclusive or				
Reg./memory and register to either	001100dw	mod reg r/m		
Immediate to register/memory	1000000w	mod 110 r/m	data	data if w=1
Immediate to accumulator	0011010w	data	data if w=1	

STRING MANIPULATION

REP Repeat	11110010
MOVS=Move byte/word	1010010w
CMPS=Compare byte/word	1010011w
SCAS=Scan byte/word	1010111w
LODS=Load byte/word to AL/AX	1010110w
STOS=Stor byte/wd from AL/A	1010101w

Mnemonics ©Intel, 1978

INSTRUCTION SET SUMMARY (Continued)

CONTROL TRANSFER

CALL - Call:	7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0
Direct within segment	1 1 1 0 1 0 0 0	disp-low	disp-high
Indirect within segment	1 1 1 1 1 1 1 1	mod 0 1 0 r/m	
Direct intersegment	1 0 0 1 1 0 1 0	offset-low	offset-high
		seg-low	seg-high
Indirect intersegment	1 1 1 1 1 1 1 1	mod 0 1 1 r/m	
JMP - Unconditional Jump:			
Direct within segment	1 1 1 0 1 0 0 1	disp-low	disp-high
Direct within segment-short	1 1 1 0 1 0 1 1	disp	
Indirect within segment	1 1 1 1 1 1 1 1	mod 1 0 0 r/m	
Direct intersegment	1 1 1 0 1 0 1 0	offset-low	offset-high
		seg-low	seg-high
Indirect intersegment	1 1 1 1 1 1 1 1	mod 1 0 1 r/m	
RET - Return from CALL			
Within segment	1 1 0 0 0 0 1 1		
Within seg. adding immed to SP	1 1 0 0 0 0 1 0	data-low	data-high
Intersegment	1 1 0 0 1 0 1 1		
Intersegment adding immediate to SP	1 1 0 0 1 0 1 0	data-low	data-high
JE/JZ - Jump on equal/zero	0 1 1 1 0 1 0 0	disp	
JL/JNGE - Jump on less/not greater or equal	0 1 1 1 1 1 0 0	disp	
JLE/JNG - Jump on less or equal/not greater	0 1 1 1 1 1 1 0	disp	
JB/JNAE - Jump on below/not above or equal	0 1 1 1 0 0 1 0	disp	
JBE/JNA - Jump on below or equal/not above	0 1 1 1 0 1 1 0	disp	
JP/JPE - Jump on parity/parity even	0 1 1 1 1 0 1 0	disp	
JO - Jump on overflow	0 1 1 1 0 0 0 0	disp	
JS - Jump on sign	0 1 1 1 1 0 0 1	disp	
JNE/JNZ - Jump on not equal/not zero	0 1 1 1 0 1 0 1	disp	
JNL/JGE - Jump on not less/greater or equal	0 1 1 1 1 0 0 1	disp	
JNLE/JG - Jump on not less or equal/greater	0 1 1 1 1 1 1 1	disp	

	7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0
JNB/JAE - Jump on not below/above or equal	0 1 1 1 0 0 1 1	disp
JNBE/JA - Jump on not below or equal/above	0 1 1 1 0 1 1 1	disp
JNP/JPO - Jump on not par/par odd	0 1 1 1 1 0 1 1	disp
JNO - Jump on not overflow	0 1 1 1 0 0 0 1	disp
JNS - Jump on not sign	0 1 1 1 1 0 0 1	disp
LOOP - Loop CX times	1 1 1 0 0 0 1 0	disp
LOOPZ/LOOPE - Loop while zero/equal	1 1 1 0 0 0 0 1	disp
LOOPNZ/LOOPNE - Loop while not zero/equal	1 1 1 0 0 0 0 0	disp
JCXZ - Jump on CX zero	1 1 1 0 0 0 1 1	disp
INT - Interrupt		
Type specified	1 1 0 0 1 1 0 1	type
Type 3	1 1 0 0 1 1 0 0	
INTO - Interrupt on overflow	1 1 0 0 1 1 1 0	
IRET - Interrupt return	1 1 0 0 1 1 1 1	
PROCESSOR CONTROL		
CLC - Clear carry	1 1 1 1 1 0 0 0	
CMC - Complement carry	1 1 1 1 0 1 0 1	
STC - Set carry	1 1 1 1 1 0 0 1	
CLD - Clear direction	1 1 1 1 1 0 0 0	
STD - Set direction	1 1 1 1 1 0 0 1	
CLI - Clear interrupt	1 1 1 1 1 0 1 0	
STI - Set interrupt	1 1 1 1 1 0 1 1	
HLT - Halt	1 1 1 1 0 4 0 0	
WAIT - Wait	1 0 0 1 1 0 1 1	
ESC - Escape to external device	1 1 0 1 1 x x x	mod x x x r/m
LOCK - Bus lock prefix	1 1 1 1 0 0 0 0	

Footnotes:

AL = 8-bit accumulator
AX = 16-bit accumulator
CX = Count register
DS = Data segment
ES = Extra segment
Above/below refers to unsigned value
Greater = more positive;
Less = less positive (more negative) signed values
if d = 1 then "to" reg; if d = 0 then "from" reg
if w = 1 then word instruction; if w = 0 then byte instruction

if s:w = 01 then 16 bits of immediate data form the operand
if s:w = 11 then an immediate data byte is sign extended to form the 16-bit operand
if v = 0 then "count" = 1, if v = 1 then "count" in (CL)
x = don't care
z is used for string primitives for comparison with ZF FLAG

SEGMENT OVERRIDE PREFIX

0 0 1 reg 1 1 0

if mod = 11 then r/m is treated as a REG field
if mod = 00 then DISP = 0*, disp-low and disp-high are absent
if mod = 01 then DISP = disp-low sign-extended to 16-bits, disp-high is absent
if mod = 10 then DISP = disp-high: disp-low

if r/m = 000 then EA = (BX) + (SI) + DISP
if r/m = 001 then EA = (BX) + (DI) + DISP
if r/m = 010 then EA = (BP) + (SI) + DISP
if r/m = 011 then EA = (BP) + (DI) + DISP
if r/m = 100 then EA = (SI) + DISP
if r/m = 101 then EA = (DI) + DISP
if r/m = 110 then EA = (BP) + DISP*
if r/m = 111 then EA = (BX) + DISP
DISP follows 2nd byte of instruction (before data if required)

*except if mod = 00 and r/m = 110 then EA = disp-high: disp-low

REG is assigned according to the following table

16-Bit (w = 1)		8-Bit (w = 0)		Segment	
000	AX	000	AL	00	ES
001	CX	001	CL	01	CS
010	DX	010	DL	10	SS
011	BX	011	BL	11	DS
100	SP	100	AH		
101	BP	101	CH		
110	SI	110	DH		
111	DI	111	BH		

Instructions which reference the flag register file as a 16-bit object use the symbol FLAGS to represent the file

FLAGS = X X X X (OF) (DF) (IF) (TF) (SF) (ZF) X (AF) X (PF) X (CF)

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iAPX 188
HIGH INTEGRATION 8-BIT MICROPROCESSOR

- **Integrated Feature Set**
  - —Enhanced 8088-2 CPU
  - —Clock Generator
  - —2 Independent, High-Speed DMA Channels
  - —Programmable Interrupt Controller
  - —3 Programmable 16-bit Timers
  - —Programmable Memory and Peripheral Chip-Select Logic
  - —Programmable Wait State Generator
  - —Local Bus Controller
- **8-Bit Data Bus Interface; 16-bit internal architecture**
- **High-Performance 8 MHz Processor**
  - —2 Times the Performance of the Standard iAPX 88
  - —2 MByte/Sec Bus Bandwidth Interface
- **Completely Object Code Compatible with All Existing iAPX 86, 88 Software**
  - —10 New Instruction Types
- **Direct Addressing Capability to 1 MByte of Memory**
- **Compatible with 8282/83/86/87, 8288, 8289 Bus Support Components**
- **Complete System Development Support**
  - —Development Software: Assembler, PL/M, Pascal, Fortran, and System Utilities
  - —In-Circuit-Emulator (ICE™ -188)
  - —iRMX™ 86, 88 Compatible (80130 OSF)
- **Optional Numeric Processor Extension**
  - —iAPX 188/20 High-Performance 80-bit Numeric Data Processor

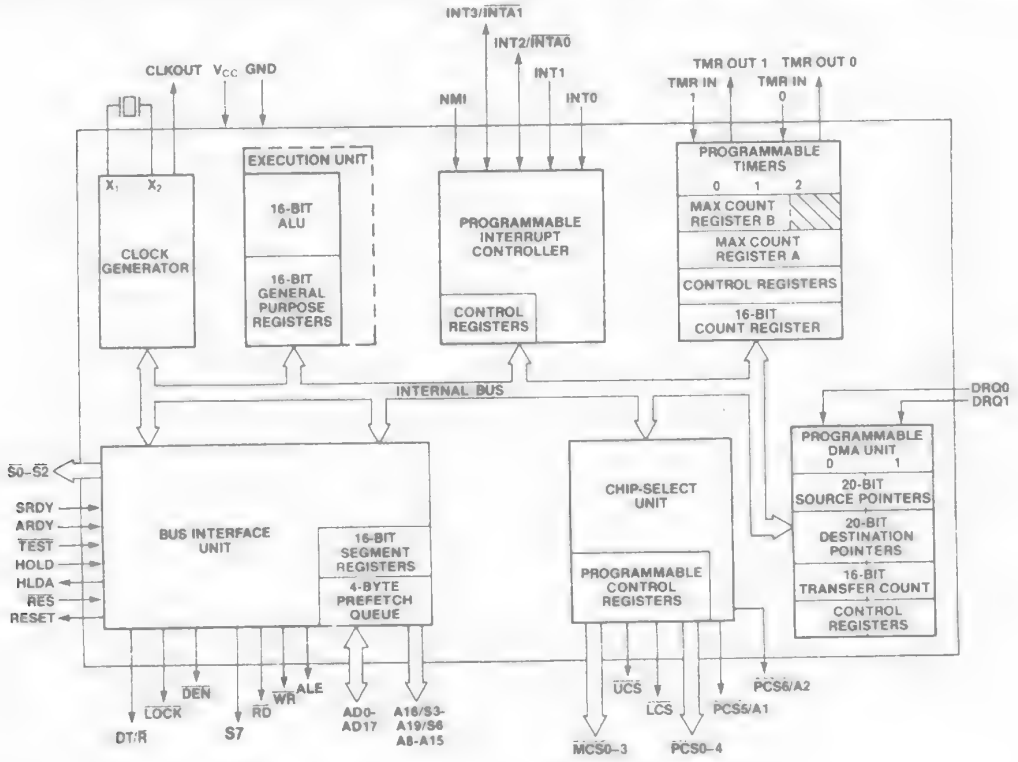

Figure 1. iAPX 188 Block Diagram

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OCTOBER 1982
ORDER NUMBER: 210706-001

The Intel iAPX 188 (80188 part number) is a highly integrated microprocessor with an 8-bit data bus interface and a 16-bit internal architecture to give high performance. The iAPX 188 effectively combines 15-20 of the most common iAPX 88 system components onto one. The 80188 provides two times greater throughput than the standard 5 MHz IAPX 88. The iAPX 188 is upward compatible with iAPX 86 and 88 software and adds 10 new instruction types to the existing set.

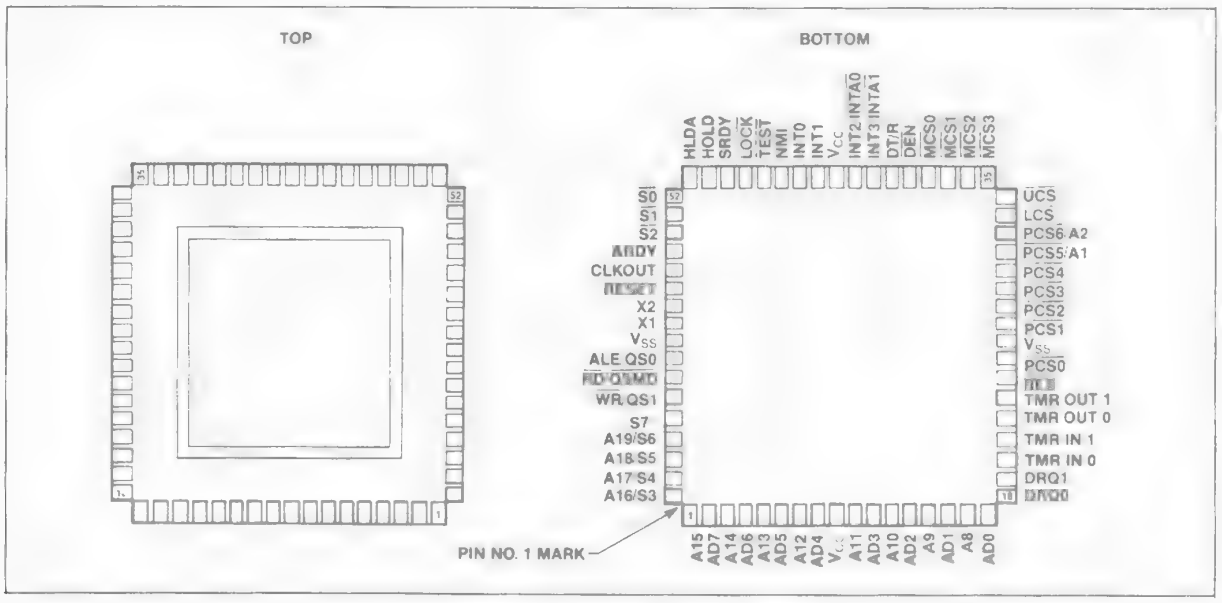

Figure 2. 80188 Pinout Diagram

Table 1. 80188 Pin Description

Symbol	Pin No.	Type	Name and Function
V_{CC}, V_{CC}	9,43	I	System Power: +5 volt power supply.
V_{SS}, V_{SS}	26,60	I	System Ground.
RESET	57	O	Reset Output indicates that the 80188 CPU is being reset, and can be used as a system reset. It is active HIGH, synchronized with the processor clock, and lasts an integer number of clock periods corresponding to the length of the $\overline{RES}$ signal.
X1, X2	59,58	I	Crystal Inputs, X1 and X2, provide an external connection for a fundamental mode parallel resonant crystal for the internal crystal oscillator. X1 can interface to an external clock instead of a crystal. The input or oscillator frequency is internally divided by two to generate the clock signal (CLKOUT).
CLKOUT	56	O	Clock Output provides the system with a 50% duty cycle waveform. All device pin timings are specified relative to CLKOUT. CLKOUT has sufficient MOS drive capabilities for the 8087 Numeric Processor Extension.
$\overline{RES}$	24	I	System Reset causes the 80188 to immediately terminate its present activity, clear the internal logic, and enter a dormant state. This signal may be asynchronous to the 80188 clock. The 80188 begins fetching instructions approximately 7 clock cycles after $\overline{RES}$ is returned HIGH. $\overline{RES}$ is required to be LOW for greater than 4 clock cycles and is internally synchronized. For proper initialization, the LOW-to-HIGH transition of $\overline{RES}$ must occur no sooner than 50 microseconds after power up. This input is provided with a Schmitt-trigger to facilitate power-on $\overline{RES}$ generation via an RC network. When $\overline{RES}$ occurs, the 80188 will drive the status lines to an inactive level for one clock, and then tri-state them.

Table 1. 80188 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{TEST}$	47	I	$\overline{TEST}$ is examined by the WAIT instruction. If the $\overline{TEST}$ input is HIGH when "WAIT" execution begins, instruction execution will suspend. $\overline{TEST}$ will be resampled until it goes LOW, at which time execution will resume. If interrupts are enabled while the 80188 is waiting for $\overline{TEST}$, interrupts will be serviced. This input is synchronized internally.
TMR IN 0, TMR IN1	20 21	I I	Timer Inputs are used either as clock or control signals, depending upon the programmed timer mode. These inputs are active HIGH (or LOW-to-HIGH transitions are counted) and internally synchronized.
TMR OUT 0, TMR OUT 1	22 23	O O	Timer outputs are used to provide single pulse or continuous waveform generation, depending upon the timer mode selected.
DRQ0 DRQ1	18 19	I I	DMA Request is driven HIGH by an external device when it desires that a DMA channel (Channel 0 or 1) perform a transfer. These signals are active HIGH, level-triggered, and internally synchronized.
NMI	46	I	Non-Maskable Interrupt is an edge-triggered input which causes a type 2 interrupt. NMI is not maskable internally. A transition from a LOW to HIGH initiates the interrupt at the next instruction boundary. NMI is latched internally. An NMI duration of one clock or more will guarantee service. This input is internally synchronized.
INT0, INT1, INT2/$\overline{INTA0}$ INT3/$\overline{INTA1}$	45,44 42 41	I I/O I/O	Maskable Interrupt Requests can be requested by strobing one of these pins. When configured as inputs, these pins are active HIGH. Interrupt Requests are synchronized internally. INT2 and INT3 may be configured via software to provide active-LOW interrupt-acknowledge output signals. All interrupt inputs may be configured via software to be either edge- or level-triggered. To ensure recognition, all interrupt requests must remain active until the interrupt is acknowleged. When iRMX mode is selected, the function of these pins changes (see Interrupt Controller section of this data sheet).
A19/S6, A18/S5, A17/S4, A16/S3	65–68	O O O O	Address Bus Outputs (16–19) and Bus Cycle Status (3–6) reflect the four most significant address bits during T_1. These signals are active HIGH. During T_2, T_3, T_W, and T_4, status information is available on these lines as encoded below: Low: S6 = Processor Cycle High: S6 = DMA Cycle S3,S4, and S5 are defined as LOW during T_2–T_4.
AD7-AD0	2,4,6,8, 11,13,15,17	I/O	Address/Data Bus (0-7) signals constitute the time mutiplexed memory or I/O address (T_1) and data (T_2, T_3, T_W, and T_4) bus. The bus is active HIGH.
A15–A8	1,3,5,7 10,12,14,16	O	Address-only Bus (8-15), containing valid address from T_1-T_4. The bus is active HIGH.
S7	64	O	This signal is always HIGH to indicate that the 80188 has an 8-bit data bus, and is tri-state OFF during bus HOLD.

Table 1. 80188 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
ALE/QS0	61	O	Address Latch Enable/Queue Status 0 is provided by the 80188 to latch the address into the 8282/8283 address latches. ALE is active HIGH. Addresses are guaranteed to be valid on the trailing edge of ALE. The ALE rising edge is generated off the rising edge of the CLKOUT immediately preceding T_1 of the associated bus cycle, effectively one-half clock cycle earlier than in the standard 80188 The trailing edge is generated off the CLKOUT rising edge in T_1 as in the 80188 Note that ALE is never floated.
$\overline{WR}$/QS1	63	O	Write Strobe/Queue Status 1 indicates that the data on the bus is to be written into a memory or an I/O device. $\overline{WR}$ is active for T_2, T_3, and T_W of any write cycle. It is active LOW, and floats during "HOLD." It is driven HIGH for one clock during Reset, and then floated. When the 80188 is in queue status mode, the ALE/QS0 and $\overline{WR}$/QS1 pins provide information about processor/instruction queue interaction. QS1 / QS0 / Queue Operation 0 / 0 / No queue operation 0 / 1 / First opcode byte fetched from the queue 1 / 1 / Subsequent byte fetched from the queue 1 / 0 / Empty the queue
$\overline{RD}$/$\overline{QSMD}$	62	O	Read Strobe indicates that the 80188 is performing a memory or I/O read cycle. $\overline{RD}$ is active LOW for T_2, T_3, and T_W of any read cycle. It is guaranteed not to go LOW in T_2 until after the Address Bus is floated. $\overline{RD}$ is active LOW, and floats during "HOLD." $\overline{RD}$ is driven HIGH for one clock during Reset, and then the output driver is floated. A weak internal pull-up mechanism on the $\overline{RD}$ line hols it HIGH when the line is not driven. During RESET the pin is sampled to determine whether the 80188 should provide ALE, $\overline{WR}$, and $\overline{RD}$, or if the Queue-Status should be provided. $\overline{RD}$ should be connected to GND to provide Queue-Status data.
ARDY	55	I	Asynchronous Ready informs the 80188 that the addressed memory space or I/O device will complete a data transfer. The ARDY input pin will accept an asynchronous input, and is active HIGH. Only the rising edge is internally synchronized by the 80188. This means that the falling edge of ARDY must be synchronized to the 80188 clock. If connected to V_{CC}, no WAIT states are inserted. Asynchronous ready (ARDY) or synchronous ready (SRDY) must be active to terminate a bus cycle. If unused, this line should be tied low.
SRDY	49	I	Synchronous Ready must be synchronized externally to the 80188. The use of SRDY provides a relaxed system-timing specification on the Ready input. This is accomplished by eliminating the one-half clock cycle which is required for internally resolving the signal level when using the ARDY input. This line is active HIGH. If this line is connected to V_{CC}, no WAIT states are inserted. Asynchronous ready (ARDY) or synchronous ready (SRDY) must be active before a bus cycle is terminated. If unused, this line should be tied low.
$\overline{LOCK}$	48	O	$\overline{LOCK}$ output indicates that other system bus masters are not to gain control of the system bus while $\overline{LOCK}$ is active LOW. The $\overline{LOCK}$ signal is requested by the LOCK prefix instruction and is activated at the beginning of the first data cycle associated with the instruction following the $\overline{LOCK}$ prefix. It remains active until the completion of the instruction following the $\overline{LOCK}$ prefix. No prefetches will occur while $\overline{LOCK}$ is asserted. $\overline{LOCK}$ is active LOW, is driven HIGH for one clock during RESET, and then floated. If unused, this line should be tied low.

Table 1. 80188 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{S0}$,$\overline{S1}$,$\overline{S2}$	52–54	O	Bus cycle status $\overline{S0}$–$\overline{S2}$ are encoded to provide bus-transaction information: 80188 Bus Cycle Status Information $\overline{S2}$ / $\overline{S1}$ / $\overline{S0}$ / Bus Cycle Initiated 0 0 0 Interrupt Acknowledge 0 0 1 Read I/O 0 1 0 Write I/O 0 1 1 Halt 1 0 0 Instruction Fetch 1 0 1 Read Data from Memory 1 1 0 Write Data to Memory 1 1 1 Passive (no bus cycle) The status pins float during "HOLD." $\overline{S2}$ may be used as a logical M/$\overline{IO}$ indicator, and $\overline{S1}$ as a DT/$\overline{R}$ indicator. The status lines are driven HIGH for one clock during Reset, and then floated until a bus cycle begins.
HOLD (input) HLDA (output)	50 51	I O	HOLD indicates that another bus master is requesting the local bus. The HOLD input is active HIGH. HOLD may be asynchronous with respect to the 80188 clock. The 80188 will issue a HLDA in response to a HOLD request at the end of T_4 or T_I. Simultaneous with the issuance of HLDA, the 80188 will float the local bus and control lines. After HOLD is detected as being LOW, the 80188 will lower HLDA. When the 80188 needs to run another bus cycle, it will again drive the local bus and control lines.
$\overline{UCS}$	34	O	Upper Memory Chip Select is an active LOW output whenever a memory reference is made to the defined upper portion (1K–256K block) of memory. This line is not floated during bus HOLD. The address range activating $\overline{UCS}$ is software programmable.
$\overline{LCS}$	33	O	Lower Memory Chip Select is active LOW whenever a memory reference is made to the defined lower portion (1K–256K) of memory. This line is not floated during bus HOLD. The address range activating $\overline{LCS}$ is software programmable.
$\overline{MCS0}$–3	38,37,36,35	O	Mid-Range Memory Chip Select signals are active LOW when a memory reference is made to the defined mid-range portion of memory (8K–512K). These lines are not floated during bus HOLD. The address ranges activating $\overline{MCS0}$–3 are software programmable.
$\overline{PCS0}$–4	25,27–30	O	Peripheral Chip Select signals 0–4 are active LOW when a reference is made to the defined peripheral area (64K byte I/O space). These lines are not floated during bus HOLD. The address ranges activating $\overline{PCS0}$–4 are software programmable.
$\overline{PCS5}$/A1	31	O	Peripheral Chip Select 5 or Latched A1 may be programmed to provide a sixth peripheral chip select, or to provide an internally latched A1 signal. The address range activating $\overline{PCS5}$ is software programmable. When programmed to provide latched A1, rather than $\overline{PCS5}$, this pin will retain the previously latched value of A1 during a bus HOLD. A1 is active HIGH.
$\overline{PCS6}$/A2	32	O	Peripheral Chip Select 6 or Latched A2 may be programmed to provide a seventh peripheral chip select, or to provide an internally latched A2 signal. The address range activating $\overline{PCS6}$ is software programmable. When programmed to provide latched A2, rather than $\overline{PCS6}$, this pin will retain the previously latched value of A2 during a bus HOLD. A2 is active HIGH.
DT/$\overline{R}$	40	O	Data Transmit/Receive controls the direction of data flow through the external 8286/8287 data bus transceiver. When LOW, data is transferred to the 80188. When HIGH the 80188 places write data on the data bus.
$\overline{DEN}$	39	O	Data Enable is provided as an 8286/8287 data bus transceiver output enable. $\overline{DEN}$ is active LOW during each memory and I/O access. $\overline{DEN}$ is HIGH whenever DT/$\overline{R}$ changes state.

FUNCTIONAL DESCRIPTION

Introduction

The following Functional Description describes the base architecture of the iAPX 188. This architecture is common to the iAPX 86, 88, and 286 microprocessor families as well. The iAPX 186 is a very high integration 8-bit microprocessor. It combines 15-20 of the most common microprocessor system components onto one chip while providing twice the performance of the standard iAPX 88. The 80188 is object code compatible with the iAPX 86, 88 microprocessors and adds 10 new instruction types to the existing iAPX 86, 88 instruction set.

iAPX 188 BASE ARCHITECTURE

The iAPX 86, 88, 186, 188, and 286 family all contain the same basic set of registers, instructions and addressing modes. The 80188 processor is upward compatible with the 8086, 8088, 80186, and 80286 CPUs.

Register Set

The 80188 base architecture has fourteen registers as shown in Figures 3a and 3b. These registers are grouped into the following categories.

General Registers
Eight 16-bit general purpose registers used to contain arithmetic and logical operands. Four of these (AX, BX, CX, and DX) can be used as 16-bit registers or split into pairs of separate 8-bit registers.

Segment Registers
Four 16-bit special purpose registers select, at any given time, the segments of memory that are immediately addressable for code, stack, and data. (For usage, refer to Memory Organization.)

Base and Index Registers
Four of the general purpose registers may also be used to determine offset addresses of operands in memory. These registers may contain base addresses or indexes to particular locations within a segment. The addressing mode selects the specific registers for operand and address calculations.

Status and Control Registers
Two 16-bit special purpose registers record or alter certain aspects of the 80188 processor state. These are the Instruction Pointer Register, which contains the offset address of the next sequential instruction to be executed, and the Status Word Register, which contains status and control flag bits (see Figures 3a and 3b).

Status Word Description

The Status Word records specific characteristics of the result of logical and arithmetic instructions (bits 0, 2, 4, 6, 7, and 11) and controls the operation of the 80188 within a given operating mode (bits 8, 9, and 10). The Status Word Register is 16-bits wide. The function of the Status Word bits is shown in Table 2.

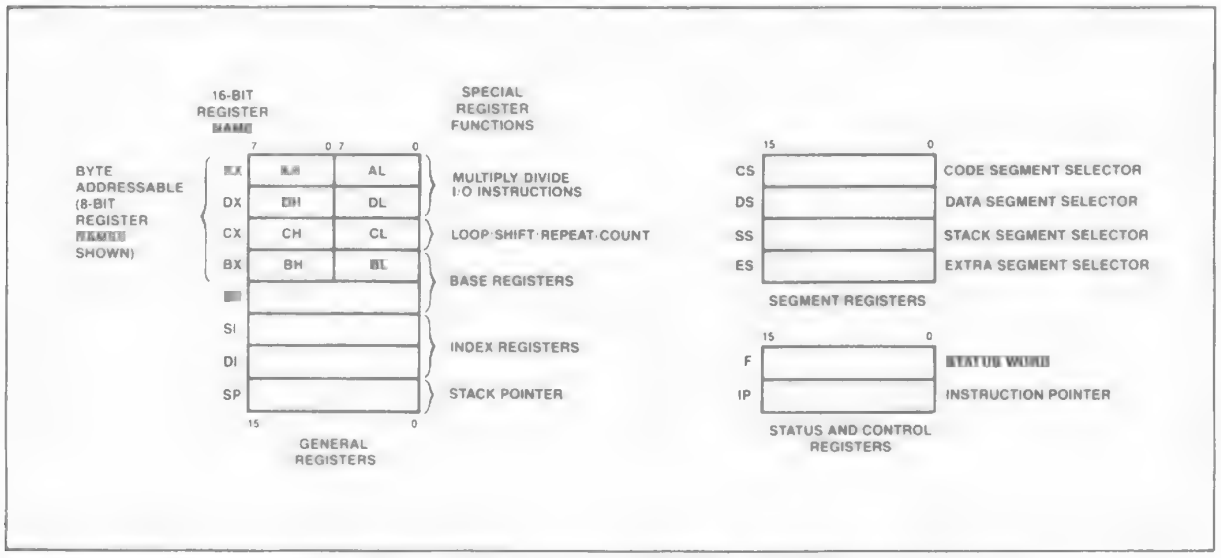

Figure 3a. 80188 General Purpose Register Set

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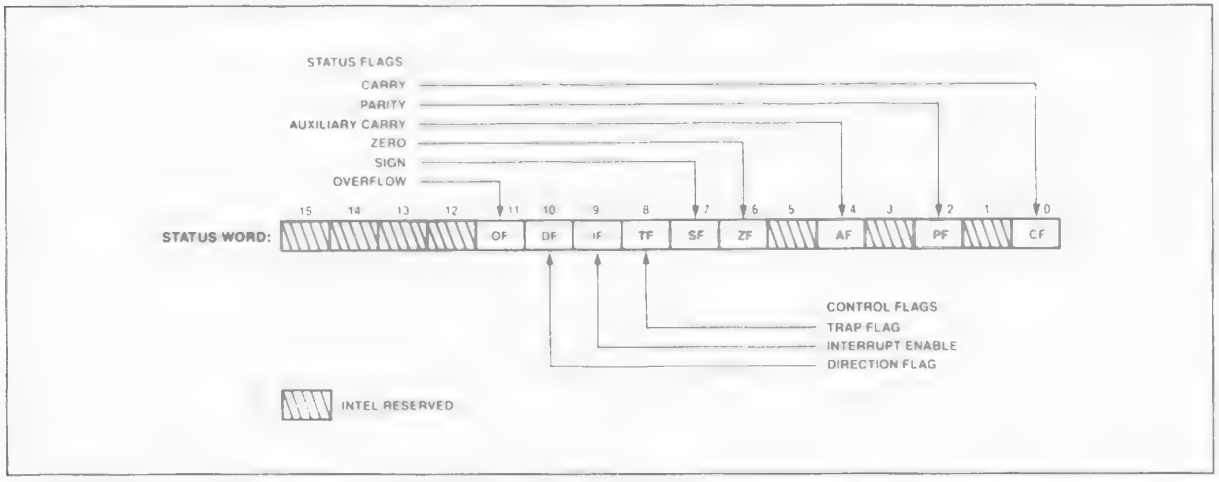


Figure 3b. Status Word Format

Table 2. Status Word Bit Functions

Bit Position	Name	Function
0	CF	Carry Flag—Set on high-order bit carry or borrow: cleared otherwise
2	PF	Parity Flag—Set if low-order 8 bits of result contain an even number of 1-bits; cleared otherwise
4	AF	Set on carry from or borrow to the low order four bits of AL; cleared otherwise
6	ZF	Zero Flag–Set if result is zero: cleared otherwise
7	SF	Sign Flag—Set equal to high-order bit of result (0 if positive, 1 if negative)
[illegible]	TF	Single Step Flag—Once set, a single step interrupt occurs after the next instruction executes. TF is cleared by the single step interrupt.
9	IF	Interrupt-enable Flag—When set, maskable interrupts will cause the CPU to transfer control to an interrupt vector specified location.
10	DF	Direction Flag—Causes string instructions to auto decrement the appropriate index register when set. Clearing DF causes auto increment.
11	OF	Overflow Flag—Set if the signed result cannot be expressed within the number of bits in the destination operand; cleared otherwise

Instruction Set

The instruction set is divided into seven categories: data transfer, arithmetic, shift/rotate/logical, string manipulation, control transfer, high-level instructions, and processor control. These categories are summarized in Figure 4.

An 80188 instruction can reference anywhere from zero to several operands. An operand can reside in a register, in the instruction itself, or in memory. Specific operand addressing modes are discussed later in this data sheet.

Memory Organization

Memory is organized in sets of segments. Each segment is a linear contiguous sequence of up to 64K (2^{16}) 8-bit bytes. Memory is addressed using a two-component address (a pointer) that consists of a 16-bit base segment and a 16-bit offset. The 16-bit base values are contained in one of four internal segment registers (code, data, stack, extra). The physical address is calculated by shifting the base value LEFT by four bits and adding the 16-bit offset value to yield a 20-bit physical address (see Figure 5). This allows for a 1 MByte physical address size.

All instructions that address operands in memory must specify the base segment and the 16-bit offset value. For speed and compact instruction encoding, the segment register used for physical address generation is implied by the addressing mode used (see Table 3). These rules follow the way programs are written (see Figure 6) as independent modules that require areas for code and data, a stack, and access to external data areas.

Special segment override instruction prefixes allow the implicit segment register selection rules to be overridden for special cases. The stack, data, and extra segments may coincide for simple programs.

GENERAL PURPOSE	
MOV	Move byte or word
PUSH	Push word onto stack
POP	Pop word off stack
PUSHA	Push all registers on stack
POPA	Pop all registers from stack
XCHG	Exchange byte or word
XLAT	Translate byte
INPUT/OUTPUT	
IN	Input byte or word
OUT	Output byte or word
ADDRESS OBJECT	
LEA	Load effective address
LDS	Load pointer using DS
LES	Load pointer using ES
FLAG TRANSFER	
LAHF	Load AH register from flags
SAHF	Store AH register in flags
PUSHF	Push flags onto stack
POPF	Pop flags off stack

ADDITION	
ADD	Add byte or word
ADC	Add byte or word with carry
INC	Increment byte or word by 1
AAA	ASCII adjust for addition
DAA	Decimal adjust for addition
SUBTRACTION	
SUB	Subtract byte or word
SBB	Subtract byte or word with borrow
DEC	Decrement byte or word by 1
NEG	Negate byte or word
CMP	Compare byte or word
AAS	ASCII adjust for subtraction
DAS	Decimal adjust for subtraction
MULTIPLICATION	
MUL	Multiply byte or word unsigned
IMUL	Integer multiply byte or word
AAM	ASCII adjust for multiply
DIVISION	
DIV	Divide byte or word unsigned
IDIV	Integer divide byte or word
AAD	ASCII adjust for division
CBW	Convert byte to word
CWD	Convert word to doubleword

MOVS	Move byte or word string
INS	Input bytes or word string
OUTS	Output bytes or word string
CMPS	Compare byte or word string
SCAS	Scan byte or word string
LODS	Load byte or word string
STOS	Store byte or word string
REP	Repeat
REPE/REPZ	Repeat while equal/zero
REPNE/REPNZ	Repeat while not equal/not zero

LOGICALS	
NOT	"Not" byte or word
AND	"And" byte or word
OR	"Inclusive or" byte or word
XOR	"Exclusive or" byte or word
TEST	"Test" byte or word
SHIFTS	
SHL/SAL	Shift logical/arithmetic left byte or word
SHR	Shift logical right byte or word
SAR	Shift arithmetic right byte or word
ROTATES	
ROL	Rotate left byte or word
ROR	Rotate right byte or word
RCL	Rotate through carry left byte or word
RCR	Rotate through carry right byte or word

FLAG OPERATIONS	
STC	Set carry flag
CLC	Clear carry flag
CMC	Complement carry flag
STD	Set direction flag
CLD	Clear direction flag
STI	Set interrupt enable flag
CLI	Clear interrupt enable flag
EXTERNAL SYNCHRONIZATION	
HLT	Halt until interrupt or reset
WAIT	Wait for $\overline{\text{TEST}}$ pin active
ESC	Escape to extension processor
LOCK	Lock bus during next instruction
NO OPERATION	
NOP	No operation
HIGH LEVEL INSTRUCTIONS	
ENTER	Format stack for procedure entry
LEAVE	Restore stack for procedure exit
BOUND	Detects values outside prescribed range

Figure 4. iAPX 188 Instruction Set

CONDITIONAL TRANSFERS		UNCONDITIONAL TRANSFERS	
JA/JNBE	Jump if above/not below nor equal	CALL	Call procedure
JAE/JNB	Jump if above or equal/not below	RET	Return from procedure
JB/JNAE	Jump if below/not above nor equal	JMP	Jump
JBE/JNA	Jump if below or equal/not above		
JC	Jump if carry	**ITERATION CONTROLS**	
JE/JZ	Jump if equal/zero		
JG/JNLE	Jump if greater/not less nor equal	LOOP	Loop
JGE/JNL	Jump if greater or equal/not less	LOOPE/LOOPZ	Loop if equal/zero
JL/JNGE	Jump if less/not greater nor equal	LOOPNE/LOOPNZ	Loop if not equal/not zero
JLE/JNG	Jump if less or equal/not greater	JCXZ	Jump if register CX = 0
JNC	Jump if not carry		
JNE/JNZ	Jump if not equal/not zero	**INTERRUPTS**	
JNO	Jump if not overflow		
JNP/JPO	Jump if not parity/parity odd	INT	Interrupt
JNS	Jump if not sign	INTO	Interrupt if overflow
JO	Jump if overflow	IRET	Interrupt return
JP/JPE	Jump if parity/parity even		
JS	Jump if sign		

Figure 4. iAPX 188 Instruction Set (continued)

To access operands that do not reside in one of the four immediately available segments, a full 32-bit pointer can be used to reload both the base (segment) and offset values.

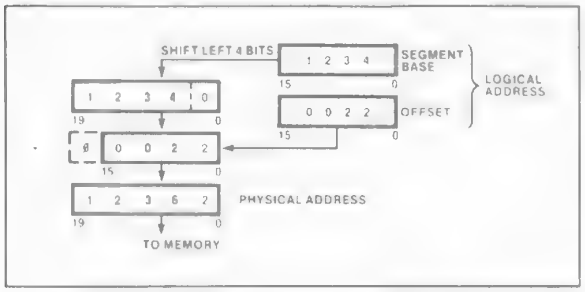


Figure 5. Two Component Address

Table 3. Segment Register Selection Rules

Memory Reference Needed	Segment Register Used	Implicit Segment Selection Rule
Instructions	Code (CS)	Instruction prefetch and immediate data.
Stack	Stack (SS)	All stack pushes and pops; any memory references which use BP Register as a base register.
External Data (Global)	Extra (ES)	All string instruction references which use the DI register as an index.
Local Data	Data (DS)	All other data references.

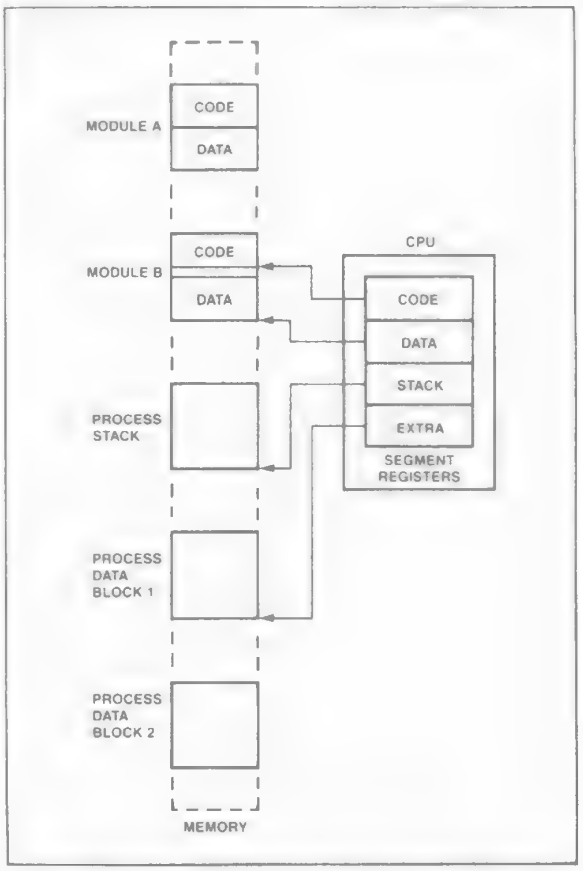


Figure 6. Segmented Memory Helps Structure Software

AFN-01483A

Addressing Modes

The 80188 provides eight categories of addressing modes to specify operands. Two addressing modes are provided for instructions that operate on register or immediate operands:

- *Register Operand Mode:* The operand is located in one of the 8- or 16-bit general registers.
- *Immediate Operand Mode:* The operand is included in the instruction.

Six modes are provided to specify the location of an operand in a memory segment. A memory operand address consists of two 16-bit components: a segment base and an offset. The segment base is supplied by a 16-bit segment register either implicity chosen by the addressing mode or explicitly chosen by a segment override prefix. The offset, also called the effective address, is calculated by summing any combination of the following three address elements:

- the *displacement* (an 8- or 16-bit immediate value contained in the instruction);
- the *base* (contents of either the BX or BP base registers); and
- the *index* (contents of either the SI or DI index registers).

Any carry out from the 16-bit addition is ignored. Eight-bit displacements are sign extended to 16-bit values.

Combinations of these three address elements define the six memory addressing modes, described below.

- *Direct Mode:* The operand's offset is contained in the instruction as an 8- or 16-bit displacement element.
- *Register Indirect Mode:* The operand's offset is in one of the registers SI, DI, BX, or BP.
- *Based Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of a base register (BX or BP).
- *Indexed Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of an index register (SI or DI).
- *Based Indexed Mode:* The operand's offset is the sum of the contents of a base register and an index register.
- *Based Indexed Mode with Displacement:* The operand's offset is the sum of a base register's contents, an index register's contents, and an 8- or 16-bit displacement.

Data Types

The 80188 directly supports the following data types:

- *Integer:* A signed binary numeric value contained in an 8-bit byte or a 16-bit word. All operations assume a 2's complement representation. Signed 32- and 64-bit integers are supported using the iAPX 188/20 Numeric Data Processor.
- *Ordinal:* An unsigned binary numeric value contained in an 8-bit byte or a 16-bit word.
- *Pointer:* A 16- or 32-bit quantity, composed of a 16-bit offset component or a 16-bit segment base component in addition to a 16-bit offset component.
- *String:* A contiguous sequence of bytes or words. A string may contain from 1 to 64K bytes.
- *ASCII:* A byte representation of alphanumeric and control characters using the ASCII standard of character representation.
- *BCD:* A byte (unpacked) representation of the decimal digits 0–9.
- *Packed BCD:* A byte (packed) representation of two decimal digits (0–9). One digit is stored in each nibble (4-bits) of the byte.
- *Floating Point:* A signed 32-, 64-, or 80-bit real number representation. (Floating point operands are supported using the iAPX 188/20 Numeric Data Processor configuration.)

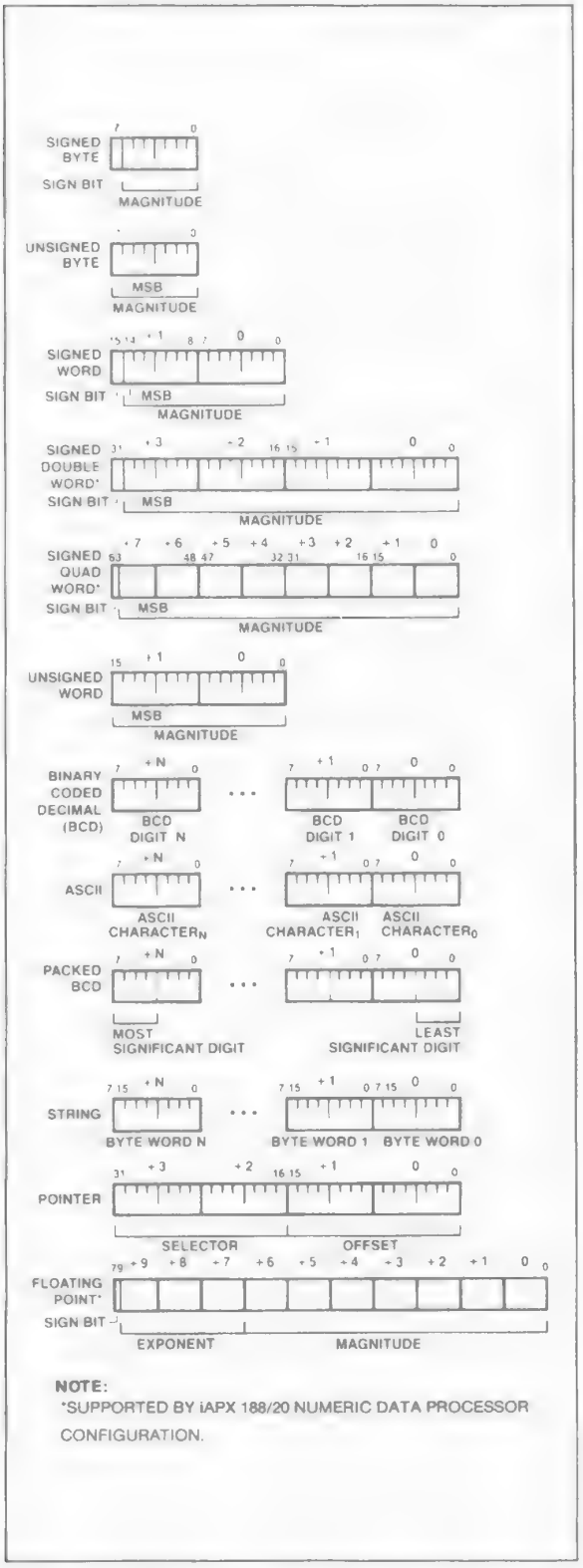
In general, individual data elements must fit within defined segment limits. Figure 7 graphically represents the data types supported by the iAPX 188.

I/O Space

The I/O space consists of 64K 8-bit or 32K 16-bit ports. Separate instructions address the I/O space with either an 8-bit port address, specified in the instruction, or a 16-bit port address in the DX register. 8-bit port addresses are zero extended such that A_{15}-A_8 are LOW. I/O port addresses 00F8(H) through 00FF(H) are reserved.

Interrupts

An interrupt transfers execution to a new program location. The old program address (CS:IP) and machine state (Status Word) are saved on the stack to allow resumption of the interrupted program. Interrupts fall into three classes: hardware initiated, INT instructions, and instruction exceptions. Hardware initiated interrupts occur in response to an external input and are classified as non-maskable or maskable.



NOTE:
*SUPPORTED BY iAPX 188/20 NUMERIC DATA PROCESSOR CONFIGURATION.

Figure 7. iAPX 188 Supported Data Types

Programs may cause an interrupt with an INT instruction. Instruction exceptions occur when an unusual condition, which prevents further instruction processing, is detected while attempting to execute an instruction. If the exception was caused by executing an ESC instruction with the ESC trap bit set in the relocation register, the return instruction will point to the ESC instruction, or to the segment override prefix immediately preceding the ESC instruction if the prefix was present. In all other cases, the return address from an exception will point at the instruction immediately following the instruction causing the exception.

A table containing up to 256 pointers defines the proper interrupt service routine for each interrupt. Interrupts 0–31, some of which are used for instruction exceptions, are reserved. Table 4 shows the 80188 predefined types and default priority levels. For each interrupt, an 8-bit vector must be supplied to the 80188 which identifies the appropriate table entry. Exceptions supply the interrupt vector internally. In addition, internal peripherals and non-cascaded external interrupts will generate their own vectors through the internal interrupt controller. INT instructions contain or imply the vector and allow access to all 256 interrupts. Maskable hardware initiated interrupts supply the 8-bit vector to the CPU during an interrupt acknowledge bus sequence. Non-maskable hardware interrupts use a predefined internally supplied vector.

Interrupt Sources

The 80188 can service interrupts generated by software or hardware. The software interrupts are generated by specific instructions (INT, ESC, unused OP, etc.) or the results of conditions specified by instructions (array bounds check, INT0, DIV, IDIV, etc.). All interrupt sources are serviced by an indirect call through an element of a vector table. This vector table is indexed by using the interrupt vector type (Table 4), multiplied by four. All hardware-generated interrupts are sampled at the end of each instruction. Thus, the software interrupts will begin service first. Once the service routine is entered and interrupts are enabled, any hardware source of sufficient priority can interrupt the service routine in progress.

The software generated 80188 interrupts are described below.

DIVIDE ERROR EXCEPTION (TYPE 0)

Generated when a DIV or IDIV instruction quotient cannot be expressed in the number of bits in the destination.

Table 4. 80188 Interrupt Vectors

Interrupt Name	Vector Type	Default Priority	Related Instructions
Divide Error Exception	0	*1	DIV, IDIV
Single Step Interrupt	1	12**2	All
NMI	2	1	All
Breakpoint Interrupt	3	*1	INT
INT0 Detected Overflow Exception	4	*1	INT0
Array Bounds Exception	5	*1	BOUND
Unused-Opcode Exception	6	*1	Undefined Opcodes
ESC Opcode Exception	7	*1***	ESC Opcodes
Timer 0 Interrupt	8	2A****	
Timer 1 Interrupt	18	2B****	
Timer 2 Interrupt	19	2C****	
Reserved	9	3	
DMA 0 Interrupt	10	4	
DMA 1 Interrupt	11	5	
INT0 Interrupt	12	6	
INT1 Interrupt	13	7	
INT2 Interrupt	14	8	
INT3 Interrupt	15	9	

NOTES:
*1. These are generated as the result of an instruction execution.
**2. This is handled as in the 8088
****3. All three timers constitute one source of request to the interrupt controller. The Timer interrupts all have the same default priority level with respect to all other interrupt sources. However, they have a defined priority ordering amongst themselves. (Priority 2A is higher priority than 2B.) Each Timer interrupt has a separate vector type number.
4. Default priorities for the interrupt sources are used only if the user does not program each source into a unique priority level.
***5. An escape opcode will cause a trap only if the proper bit is set in the peripheral control block relocation register.

SINGLE-STEP INTERRUPT (TYPE 1)
Generated after most instructions if the TF flag is set. Interrupts will not be generated after prefix-instructions (e.g., REP), instructions which modify segment registers (e.g., POP DS), or the WAIT instruction.

NON-MASKABLE INTERRUPT—NMI (TYPE 2)
An external interrupt source which cannot be masked.

BREAKPOINT INTERRUPT (TYPE 3)
A one-byte version of the INT instruction. It uses 12 as an index into the service routine address table (because it is a type 3 interrupt).

INT0 DETECTED OVERFLOW EXCEPTION (TYPE 4)
Generated during an INT0 instruction if the OF bit is set.

ARRAY BOUNDS EXCEPTION (TYPE 5)
Generated during a BOUND instruction if the array index is outside the array bounds. The array bounds are located in memory at a location indicated by one of the instruction operands. The other operand indicates the value of the index to be checked.

UNUSED OPCODE EXCEPTION (TYPE 6)
Generated if execution is attempted on undefined opcodes.

ESCAPE OPCODE EXCEPTION (TYPE 7)
Generated if execution is attempted of ESC opcodes (D8H–DFH). This exception will only be generated if a bit in the relocation register is set. The return address of this exception will point to the ESC instruction causing the exception. If a segment override prefix preceded the ESC instruction, the return address will point to the segment override prefix.

Hardware-generated interrupts are divided into two groups: maskable interrupts and non-maskable interrupts. The 80188 provides maskable hardware interrupt request pins INT0–INT3. In addition, maskable interrupts may be generated by the 80188 integrated DMA controller and the integrated timer unit. The vector types for these interrupts is shown in Table 4. Software enables these inputs by setting the interrupt flag bit (IF) in the Status Word. The interrupt controller is discussed in the peripheral section of this data sheet.

Further maskable interrupts are disabled while servicing an interrupt because the IF bit is reset as part of the response to an interrupt or exception. The saved Status Word will reflect the enable status of the processor prior to the interrupt. The interrupt flag will remain zero unless specifically set. The interrupt return instruction restores the Status Word, thereby restoring the original status of IF bit. If the interrupt return re-enables interrupts, and another interrupt is pending, the 80188 will immediately service the highest-priority interrupt pending, i.e., no instructions of the main line program will be executed.

Non-Maskable Interrupt Request (NMI)

A non-maskable interrupt (NMI) is also provided. This interrupt is serviced regardless of the state of the IF bit. A typical use of NMI would be to activate a power failure routine. The activation of this input

causes an interrupt with an internally supplied vector value of 2. No external interrupt acknowledge sequence is performed. The IF bit is cleared at the beginning of an NMI interrupt to prevent maskable interrupts from being serviced.

Single-Step Interrupt

The 80188 has an internal interrupt that allows programs to execute one instruction at a time. It is called the single-step interrupt and is controlled by the single-step flag bit (TF) in the Status Word. Once this bit is set, an internal single-step interrupt will occur after the next instruction has been executed. The interrupt clears the TF bit and uses an internally supplied vector of 1. The IRET instruction is used to set the TF bit and transfer control to the next instruction to be single-stepped.

Initialization and Processor Reset

Processor initialization or startup is accomplished by driving the $\overline{RES}$ input pin LOW. $\overline{RES}$ forces the 80188 to terminate all execution and local bus activity. No instructionor bus activity will occur as long as $\overline{RES}$ is active. After $\overline{RES}$ becomes inactive and an internal processing interval elapses, the 80188 begins execution withthe instruction at physical location FFFF0(H). RES also sets some registers to predefined values as shown in Table 5.

Table 5. 80188 Initial Register State after RESET

Status Word	F002(H)
Instruction Pointer	0000(H)
Code Segment	FFFF(H)
Data Segment	0000(H)
Extra Segment	0000(H)
Stack Segment	0000(H)
Relocation Register	20FF(H)
UMCS	FFFB(H)

THE 80188 COMPARED TO THE 80186

The 80188 CPU is an 8-bit processor designed around the 80186 internal structure. Most internal functions of the 80188 are identical to the equivalent 80186 functions. The 80188 handles the external bus the same way the 80186 does with the distinction of handling only 8 bits at a time. Sixteen bit operands are fetched or written in two consecutive bus cycles. Both processors will appear identical to the software engineer, with the exception of execution time. The internal register structure is identical and all instructions have the same end result. The differences between the 80188 and 80186 are outlined below. Internally, there are three differences between the 80188 and the 80186. All changes are related to the 8-bit bus interface.

- The queue length is 4 bytes in the 80188, whereas the 80186 queue contains 6 bytes, or three words. The queue was shortened to prevent overuse of the bus by the BIU when prefetching instructions. This was required because of the additional time necessary to fetch instructions 8 bits at a time.
- To further optimize the queue, the prefetching algorithm was changed. The 80188 BIU will fetch a new instruction to load into the queue each time there is a 1-byte hole (space available) in the queue. The 80186 waits until a 2-byte space is available.
- The internal execution time of the instruction is affected by the 8-bit interface. All 16-bit fetches and writes from/to memory take an additional four clock cycles. The CPU may also be limited by the speed of instruction fetches when a series of simple operations occur. When the more sophisticated instructions of the 80188 are being used, the queue has time to fill and the execution proceeds as fast as the execution unit will allow.

The 80188 and 80186 are completely software compatible by virture of their identical execution units. Software that is system dependent may not be completely transferable, but software that is not system dependent will operate equally well on an 80188 or an 80186.

The hardware interface of the 80188 contains the major differences between the two CPUs. The pin assignments are nearly identical, however, with the following functional changes.

- A8-A15—These pins are only address outputs on the 80188. These address lines are latched internally and remain valid throughout a bus cycle in a manner similar to the 8085 upper address lines.
- $\overline{BHE}$ has no meaning on the 80188 and has been eliminated.

iAPX 188 CLOCK GENERATOR

The iAPX 188 provides an on-chip clock generator for both internal and external clock generation. The clock generator features a crystal oscillator, a divide-by-two counter, synchronous and asynchronous ready inputs, and reset circuitry.

Oscillator

The oscillator circuit of the iAPX 188 is designed to be used with a parallel resonant fundamental mode crystal. This is used as the time base for the iAPX 186. The crystal frequency selected will be double the CPU clock frequency. Use of an LC or RC circuit is not recommended with this oscillator. If an external oscillator is used, it can be connected directly to input pin X1 in lieu of a crystal. The output of the oscillator is not directly available outside the iAPX 188. The recommended crystal configuration is shown in Figure 8.

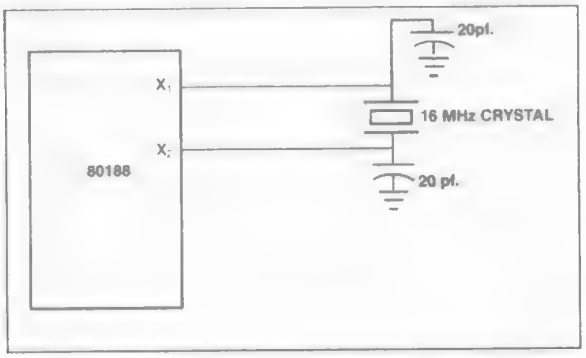


Figure 8. Recommended iAPX 188 Crystal Configuration

Clock Generator

The iAPX 188 clock generator provides the 50% duty cycle processor clock for the iAPX 188. It does this by dividing the oscillator output by 2 forming the symmetrical clock. If an external oscillator is used, the state of the clock generator will change on the falling edge of the oscillator signal. The CLKOUT pin provides the processor clock signal for use outside the iAPX 188. This may be used to drive other system components. All timings are referenced to the output clock.

READY Synchronization

The iAPX 188 provides both synchronous and asynchronous ready inputs. Asynchronous ready synchronization is accomplished by circuitry which samples ARDY in the middle of T_2, T_3 and again in the middle of each T_w until ARDY is sampled HIGH. One-half CLKOUT cycle of resolution time is used. Full synchronization is performed only onthe rising edge of ARDY, i.e., the falling edge of ARDY must be synchronized to the CLKOUT signal if it will occur during T_2, T_3 or T_w. HIGH-to-LOW transitions of ARDY must be performed synchronously to the CPU clock.

A second ready input (SRDY) is provided to interface with externally synchronized ready signals. This input is sampled at the end of T_2, T_3 and again at the end of each T_w until it is sampled HIGH. By using this input rather than the asynchronous ready input, the half-clock cycle resolution time penalty is eliminated.

This input must satisfy set-up and hold times to guarantee proper operation of the circuit.

In addition, the iAPX 188, as part of the integrated chip-select logic, has the capability to program WAIT states for memory and peripheral blocks. This is discussed in the Chip Select/Ready Logic description.

RESET Logic

The iAPX 188 provides both a $\overline{RES}$ input pin and a synchronized RESET pin for use with other system components. The $\overline{RES}$ input pin on the iAPX 188 is provided with hysteresis in order to facilitate power-on Reset generation via an RC network. RESET is guaranteed to remain active for at least five clocks given a $\overline{RES}$ input of at least six clocks. RESET may be delayed up to two and one-half clocks behind $\overline{RES}$.

Multiple iAPX 188 processors may be synchronized through the $\overline{RES}$ input pin, since this input resets both the processor and divide-by-two internal counter in the clock generator. In order to insure that the divide-by-two counters all begin counting at the same time, the active going edge of $\overline{RES}$ must satisfy a 25 ns setup time before the falling edge of the 80188 clock input. In addition, in order to insure that all CPUs begin executing in the same clock cycle, the reset must satisfy a 25 ns setup time before the rising edge of the CLKOUT signal of all the processors.

LOCAL BUS CONTROLLER

The iAPX 188 provides a local bus controller to generate the local bus control signals. In addition, it employs a HOLD/HLDA protocol for relinquishing the local bus to other bus masters. It also provides control lines that can be used to enable external buffers and to direct the flow of data on and off the local bus.

Memory/Peripheral Control

The iAPX 188 provides ALE, $\overline{RD}$, and $\overline{WR}$ bus control signals. The $\overline{RD}$ and $\overline{WR}$ signals are used to strobe data from memory to the iAPX 188 or to strobe data from the iAPX 188 to memory. The ALE line provides a strobe to address latches for the multiplexed address/data bus. The iAPX 188 local bus controller does not provide a memory/$\overline{I/O}$ signal. If this is required, the user will have to use the $\overline{S2}$ signal (which will require external latching), make the memory and I/O spaces nonoverlapping, or use only the integrated chip-select circuitry.

Transceiver Control

The iAPX 188 generates two control signals to be connected to 8286/8287 transceiver chips. This capability allows the addition of transceivers for extra buffering without adding external logic. These control lines, DT/$\overline{R}$ and $\overline{DEN}$, are generated to control the flow of data through the transceivers. The operation of these signals is shown in Table 6.

Table 6. Transceiver Control Signals Description

Pin Name	Function
$\overline{DEN}$ (Data Enable)	Enables the output drivers of the transceivers. It is active LOW during memory, I/O, or INTA cycles.
DT/$\overline{R}$ (Data Transmit/ Receive)	Determines the direction of travel through the transceivers. A HIGH level directs data away from the processor during write operations, while a LOW level directs data toward the processor during a read operation.

Local Bus Arbitration

The iAPX 188 uses a HOLD/HLDA system of local bus exchange. This provides an asynchronous bus exchange mechanism. This means multiple masters utilizing the same bus can operate at separate clock frequencies. The iAPX 188 provides a single HOLD/HLDA pair through which all other bus masters may gain control of the local bus. This requires external circuitry to arbitrate which external device will gain control of the bus from the iAPX 188 when there is more than one alternate local bus master. When the iAPX 188 relinquishes control of the local bus, it floats $\overline{DEN}$, $\overline{RD}$, $\overline{WR}$, $\overline{S0}$-$\overline{S2}$, $\overline{LOCK}$, AD0-AD-15, A16-A19, $\overline{S7}$, and DT/$\overline{R}$ to allow another master to drive these lines directly.

The iAPX 188 HOLD latency time, i.e., the time between HOLD request and HOLD acknowledge, is a function of the activity occurring in the processor when the HOLD request is received. A HOLD request is the highest-priority activity request which the processor may receive: higher than instruction fetching or internal DMA cycles. However, if a DMA cycle is in progress, the iAPX 188 will complete the transfer before relinquishing the bus. This implies that if a HOLD request is received just as a DMA transfer begins, the HOLD latency time can be as great as 4 bus cycles. This will occur if a DMA word transfer operation is taking place from an odd address to an odd address. This is a total of 16 clocks or more, if WAIT states are required. In addition, if locked transfers are performed, the HOLD latency time will be increased by the length of the locked transfer.

Local Bus Controller and Reset

Upon receipt of a RESET pulse from the $\overline{RES}$ input, the local bus controller will perform the following actions:

- Drive $\overline{DEN}$, $\overline{RD}$, and $\overline{WR}$ HIGH for one clock cycle, then float.

  NOTE: $\overline{RD}$ is also provided with an internal pull-up device to prevent the processor from inadvertently entering Queue Status mode during reset.

- Drive $\overline{S0}$–$\overline{S2}$ to the passive state (all HIGH) and then float.
- Drive $\overline{LOCK}$ HIGH and then float.
- Tristate AD0-7, A8-19, S7, DT/$\overline{R}$.
- Drive ALE LOW (ALE is never floated).
- Drive HLDA LOW.

INTERNAL PERIPHERAL INTERFACE

All the iAPX 188 integrated peripherals are controlled via 16-bit registers contained within an internal 256-byte control block. This control block may be mapped into either memory or I/O space. Internal logic will recognize the address and respond to the bus cycle. During bus cycles to internal registers, the bus controller will signal the operation externally (i.e., the $\overline{RD}$, $\overline{WR}$, status, address, data, etc., lines will be driven as in a normal bus cycle), but D_{7-0}, SRDY, and ARDY will be ignored. The base address of the control block must be on an even 256-byte boundary (i.e., the lower 8 bits of the base address are all zeros). All of the defined registers within this control block may be read or written by the 80188 CPU at any time. The location of any register contained within the 256-byte control block is determined by the current base address of the control block.

The control block base address is programmed via a 16-bit relocation register contained within the control block at offset FEH from the base address of the control block (see Figure 9). It provides the upper 12 bits of the base address of the control block. Note that mapping the control register block into an address range corresponding to a chip-select range is not recommended (the chip select circuitry is discussed later in this data sheet). In addition, bit 12 of this register determines whether the control block will be mapped into I/O or memory space. If this bit is 1, the control block will be located in memory space, whereas if the bit is 0, the control block will be located in I/O space. If the control register block is mapped into I/O space, the upper 4 bits of the base address must be programmed as 0 (since I/O addresses are only 16 bits wide).

In addition to providing relocation information for the control block, the relocation register contains bits which place the interrupt controller into iRMX mode, and cause the CPU to interrupt upon encountering ESC instructions. At RESET, the relocation register is set to 20FFH. This causes the control block to start at FF00H in I/O space. An offset map of the 256-byte control register block is shown in Figure 10.

The integrated iAPX 188 peripherals operate semi-autonomously from the CPU. Access to them for the most part is via software read/write of the control and data locations in the control block. Most of these registers can be both read and written. A few dedicated lines, such as interrupts and DMA request provide real-time communication between the CPU and peripherals as in a more conventional system utilizing discrete peripheral blocks. The overall interaction and function of the peripheral blocks has not substantially changed. The data access from/to the 256-byte internal control block will always be 16-bit and done in one bus cycle.

CHIP-SELECT/READY GENERATION LOGIC

The iAPX 188 contains logic which provides programmable chip-select generation for both memories and peripherals. In addition, it can be programmed to provide READY (or WAIT state) generation. It can also provide latched address bits A1 and A2. The chip-select lines are active for all memory and I/O cycles in their programmed areas, whether they be generated by the CPU or by the integrated DMA unit.

Memory Chip Selects

The iAPX 188 provides 6 memory chip select outputs for 3 address areas: upper memory, lower memory, and midrange memory. One each is provided for upper memory and lower memory, while four are provided for midrange memory.

The range for each chip select is user-programmable and can be set to 2K, 4K, 8K, 16K, 32K, 64K, 128K (plus 1K and 256K for upper and lower chip selects). In addition, the beginning or base address of the midrange memory chip select may also be selected. Only one chip select may be programmed to be active for any memory location at a time. All chip select sizes are in bytes.

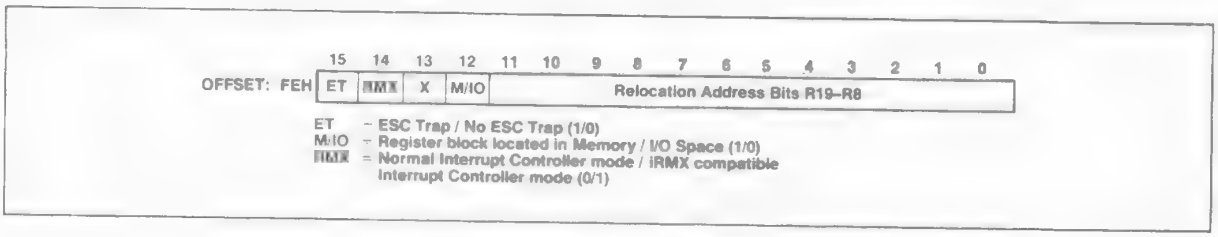


Figure 9. Relocation Register

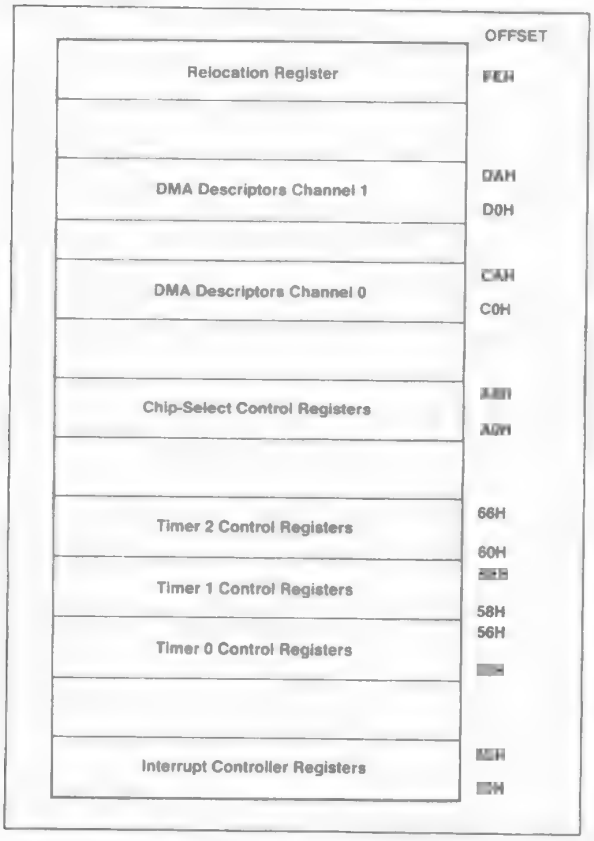


Figure 10. Internal Register Map

Upper Memory $\overline{CS}$

The iAPX 188 provides a chip select, called $\overline{UCS}$, for the top of memory. The top of memory is usually used as the system memory because after reset the iAPX 188 begins executing at memory location FFFF0H.

The upper limit of memory defined by this chip select is always FFFFFH, while the lower limit is programmable. By programming the lower limit, the size of the select block is also defined. Table 7 shows the relationship between the base address selected and the size of the memory block obtained.

Table 7. UMCS Programming Values

Starting Address (Base Address)	Memory Block Size	UMCS Value (Assuming R0=R1=R2=0)
FFC00	1K	FFF8H
FF800	2K	FFB8H
FF000	4K	FF38H
FE000	8K	FE38H
FC000	16K	FC38H
F8000	32K	F838H
F0000	64K	F038H
E0000	128K	E038H
C0000	256K	C038H

The lower limit of this memory block is defined in the UMCS register (see Figure 11). This register is at offset A0H in the internal control block. The legal values for bits 6–13 and the resulting starting address and memory block sizes are given in Table 7. Any combination of bits 6–13 not shown in Table 7 will result in undefined operation. After reset, the UMCS register is programmed for a 1K area. It must be reprogrammed if a larger upper memory area is desired.

Any internally generated 20-bit address whose upper 16 bits are greater than or equal to UMCS (with bits 0–5 "0") will cause UCS to be activated. UMCS bits R2–R0 are used to specify READY mode for the area of memory defined by this chip-select register, as explained below.

Lower Memory $\overline{CS}$

The iAPX 188 provides a chip select for low memory called $\overline{LCS}$. The bottom of memory contains the interrupt vector table, starting at location 00000H.

The lower limit of memory defined by this chip select is always 0H, while the upper limit is programmable. By programming the upper limit, the size of the memory block is also defined. Table 8 shows the relationship between the upper address selected and the size of the memory block obtained.

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Table 8. LMCS Programming Values

Upper Address	Memory Block Size	LMCS Value (Assuming R0=R1=R2=0)
003FFH	1K	0038H
007FFH	2K	0078H
00FFFH	4K	00F8H
01FFFH	8K	01F8H
03FFFH	16K	03F8H
07FFFH	32K	07F8H
0FFFFH	64K	0FF8H
1FFFFH	128K	1FF8H
3FFFFH	256K	3FF8H

The upper limit of this memory block is defined in the LMCS register (see Figure 12). This register is at offset A2H in the internal control block. The legal values for bits 6–15 and the resulting upper address and memory block sizes are given in Table 8. Any combination of bits 6–15 not shown in Table 8 will result in undefined operation. After reset, the LMCS register value is undefined. However, the $\overline{LCS}$ chip-select line will not become active until the LMCS register is accessed.

Any internally generated 20-bit address whose upper 16 bits are less than or equal to LMCS (with bits 0–5 "1") will cause $\overline{LCS}$ to be active. LMCS register bits R2–R0 are used to specify the READY mode for the area of memory defined by this chip-select register.

Mid-Range Memory $\overline{CS}$

The iAPX 188 provides four $\overline{MCS}$ lines which are active within a user-locatable memory block. This block can be located anywhere within the iAPX 188 1M byte memory address space exclusive of the areas defined by $\overline{UCS}$ and $\overline{LCS}$. Both the base address and size of this memory block are programmable.

The size of the memory block defined by the mid-range select lines, as shown in Table 9, is determined by bits 8–14 of the MPCS register (see Figure 13). This register is at location A8H in the internal control block. One and only one of bits 8–14 must be set at a time. Unpredictable operation of the $\overline{MCS}$ lines will otherwise occur. Each of the four chip-select lines is active for one of the four equal contiguous divisions of the mid-range block. Thus, if the total block size is 32K, each chip select is active for 8K of memory with $\overline{MCS0}$ being active for the first range and $\overline{MCS3}$ being active for the last range.

The EX and MS in MPCS relate to peripheral functionality as descibed a later section.

Table 9. MPCS Programming Values

Total Block Size	Individual Select Size	MPCS Bits 14-8
8K	2K	0000001B
16K	4K	0000010B
32K	8K	0000100B
64K	16K	0001000B
128K	32K	0010000B
256K	64K	0100000B
512K	128K	1000000B

The base address of the mid-range memory block is defined by bits 15–9 of the MMCS register (see Figure 14). This register is at offset A6H in the internal control block. These bits correspond to bits A19–A13 of the 20-bit memory address. Bits A12–A0 of the base address are always 0. The base address may be set at any integer multiple of the size of the total memory block selected. For example, if the mid-range block size is 32K (or the size of the block for which each $\overline{MCS}$ line is active is 8K), the block could be located at 10000H or 18000H, but not at 14000H, since the first few integer multiples of a 32K memory block are 0H, 8000H, 10000H, 18000H, etc. After reset, the contents of both of these registers is undefined. However, none of the $\overline{MCS}$ lines will be active until both the MMCS and MPCS registers are accessed.

Figure 11. UMCS Register

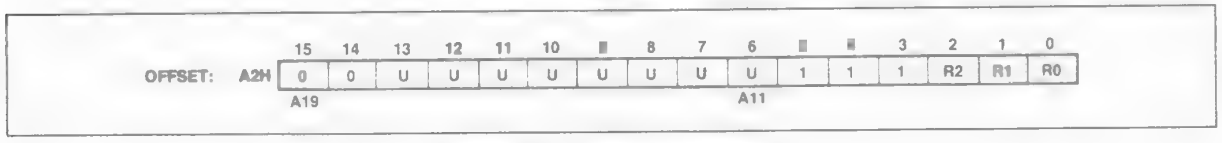

Figure 12. LMCS Register

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OFFSET:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A8H	1	M6	M5	M4	M3	M2	M1	M0	EX	MS	1	1	1	R2	R1	R0

Figure 13. MPCS Register

OFFSET:	15						9						3			0
A6H	U	U	U	U	U	U	U	1	1	1	1	1	1	R2	R1	R0
	A19						A13									

Figure 14. MMCS Register

MMCS bits R2–R0 specify READY mode of operation for all mid-range chip selects. All devices in mid-range memory must use the same number of WAIT states.

The 512K block size for the mid-range memory chip selects is a special case. When using 512K, the base address would have to be at either locations 00000H or 80000H. If it were to be programmed at 00000H when the $\overline{LCS}$ line was programmed, there would be an internal conflict between the $\overline{LCS}$ ready generation logic and the $\overline{MCS}$ ready generation logic. Likewise, if the base address were programmed at 80000H, there would be a conflict with the $\overline{UCS}$ ready generation logic. Since the $\overline{LCS}$ chip-select line does not become active until programmed, while the $\overline{UCS}$ line is active at reset, the memory base can be set only at 00000H. If this base address is selected, however, the $\overline{LCS}$ range must not be programmed.

Peripheral Chip Selects

The iAPX 188 can generate chip selects for up to seven peripheral devices. These chip selects are active for seven contiguous blocks of 128 bytes above a programmable base address. This base address may be located in either memory or I/O space.

Seven $\overline{CS}$ lines called $\overline{PCS0}$–6 are generated by the iAPX 188. The base address is user-programmable; however it can only be a multiple of 1K bytes, i.e., the least significant 10 bits of the starting address are always 0.

$\overline{PCS5}$ and $\overline{PCS6}$ can also be programmed to provide latched address bits A1, A2. If so programmed, they cannot be used as peripheral selects. These outputs can be connected directly to the A0, A1 pins used for selecting internal registers of 8-bit peripheral chips. This scheme simplifies the hardware interface because the 8-bit registers of peripherals are simply treated as 16-bit registers located on even boundaries in I/O space or memory space where only the lower 8-bits of the register are significant: the upper 8-bits are "don't cares."

The starting address of the peripheral chip-select block is defined by the PACS register (see Figure 15). This register is located at offset A4H in the internal control block. Bits 15–6 of this register correspond to bits 19–10 of the 20-bit Programmable Base Address (PBA) of the peripheral chip-select block. Bits 9–0 of the PBA of the peripheral chip-select block are all zeros. If the chip-select block is located in I/O space, bits 12–15 must be programmed zero, since the I/O address is only 16 bits wide. Table 10 shows the address range of each peripheral chip select with respect to the PBA contained in PACS register.

OFFSET:	15									6	5	4	3	2	1	0
A4H	U	U	U	U	U	U	U	U	U	U	1	1	1	R2	R1	R0
	A19									A10						

Figure 15. PACS Register

The user should program bits 15–6 to correspond to the desired peripheral base location. PACS bits 0–2 are used to specify READY mode for $\overline{PCS0}$–$\overline{PCS3}$.

Table 10. PCS Address Ranges

PCS Line	Active between Locations
PCS0	PBA — PBA+127
PCS1	PBA+128 — PBA+255
PCS2	PBA+256 — PBA+383
PCS3	PBA+384 — PBA+511
PCS4	PBA+512 — PBA+639
PCS5	PBA+640 — PBA+767
PCS6	PBA+768 — PBA+895

The mode of operation of the peripheral chip selects is defined by the MPCS register (which is also used to set the size of the mid-range memory chip-select block, see Figure 16). This register is located at offset A8H in the internal control block. Bit 7 is used to select the function of $\overline{PCS5}$ and $\overline{PCS6}$, while bit 6 is used to select whether the peripheral chip selects are mapped into memory or I/O space. Table 11 describes the programming of these bits. After reset, the contents of both the MPCS and the PACS registers are undefined, however none of the PCS lines will be active until both of the MPCS and PACS registers are accessed.

Table 11. MS, EX Programming Values

Bit	Description
MS	1 = Peripherals mapped into memory space. 0 = Peripherals mapped into I/O space.
EX	0 = 5 $\overline{PCS}$ lines. A1, A2 provided. 1 = 7 $\overline{PCS}$ lines. A1, A2 are not provided.

MPCS bits 0–2 are used to specify READY mode for $\overline{PCS4}$–$\overline{PCS6}$ as outlined below.

READY Generation Logic

The iAPX 188 can generate a "READY" signal internally for each of the memory or peripheral $\overline{CS}$ lines. The number of WAIT states to be inserted for each peripheral or memory is programmable to provide 0–3 wait states for all accesses to the area for which the chip select is active. In addition, the iAPX 188 may be programmed to either ignore external READY for each chip-select range individually or to factor external READY with the integrated ready generator.

READY control consists of 3 bits for each $\overline{CS}$ line or group of lines generated by the iAPX 188. The interpretation of the ready bits is shown in Table 12.

Table 12. READY Bits Programming

R2	R1	R0	Number of WAIT States Generated
0	0	0	0 wait states, external RDY also used.
0	0	1	1 wait state inserted, external RDY also used.
0	1	0	2 wait states inserted, external RDY also used.
0	1	1	3 wait states inserted, external RDY also used.
1	0	0	0 wait states, external RDY ignored.
1	0	1	1 wait state inserted, external RDY ignored.
1	1	0	2 wait states inserted, external RDY ignored.
1	1	1	3 wait states inserted, external RDY ignored.

The internal ready generator operates in parallel with external READY, not in series if the external READY is used (R2 = 0). This means, for example, if the internal generator is set to insert two wait states, but activity on the external READY lines will insert four wait states, the processor will only insert four wait states, not six. This is because the two wait states generated by the internal generator overlapped the first two wait states generated by the external ready signal. Note that the external ARDY and SRDY lines are always ignored during cycles accessing internal peripherals.

R2–R0 of each control word specifies the READY mode for the corresponding block, with the exception of the peripheral chip selects: R2–R0 of PACS set the $\overline{PCS0}$–3 READY mode, R2–R0 of MPCS set the $\overline{PCS4}$–6 READY mode.

Chip Select/Ready Logic and Reset

Upon reset, the Chip-Select/Ready Logic will perform the following actions:

- All chip-select outputs will be driven HIGH.
- Upon leaving RESET, the $\overline{UCS}$ line will be programmed to provide chip selects to a 1K block with the accompanying READY control bits set at 011 to

		15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OFFSET:	A8H	1	M6	M5	M4	M3	M2	M1	M0	EX	MS	1	1	1	R2	R1	R0

Figure 16. MPCS Register

allow the maximum number of internal wait states in conjunction with external Ready consideration (i.e., UMCS resets to FFFBH).

- No other chip select or READY control registers have any predefined values after RESET. They will not become active until the CPU accesses their control registers. Both the PACS and MPCS registers must be accessed before the $\overline{PCS}$ lines will become active.

DMA CHANNELS

The 80188 DMA controller provides two independent high-speed DMA channels. Data transfers can occur between memory and I/O spaces (e.g., Memory to I/O) or within the same space (e.g., Memory to Memory or I/O to I/O). Each DMA channel maintains both a 20-bit source and destination pointer which can be optionally incremented or decremented after each data transfer Each data transfer consumes 2 bus cycles (a minimum of 8 clocks), one cycle to fetch data and the other to store data. This provides a maximum data transfer rate of one MByte/sec.

DMA Operation

Each channel has six registers in the control block which define each channel's specific operation. The control registers consist of a 20-bit Source pointer (2 words), a 20-bit Destination pointer (2 words), a 16-bit Transfer Counter, and a 16-bit Control Word. The format of the DMA Control Blocks is shown in Table 13. The Transfer Count Register (TC) specifies the number of DMA transfers to be performed. Up to 64K byte transfers can be performed with automatic termination. The Control Word defines the channel's operation (see Figure 18). All registers may be modified or altered during any DMA activity. Any changes made to these registers will be reflected immediately in DMA operation.

Table 13. DMA Control Block Format

Register Name	Register Address	
	Ch. 0	Ch. 1
Control Word	CAH	DAH
Transfer Count	C8H	D8H
Destination Pointer (upper 4 bits)	C6H	D6H
Destination Pointer	C4H	D4H
Source Pointer (upper 4 bits)	C2H	D2H
Source Pointer	C0H	D0H

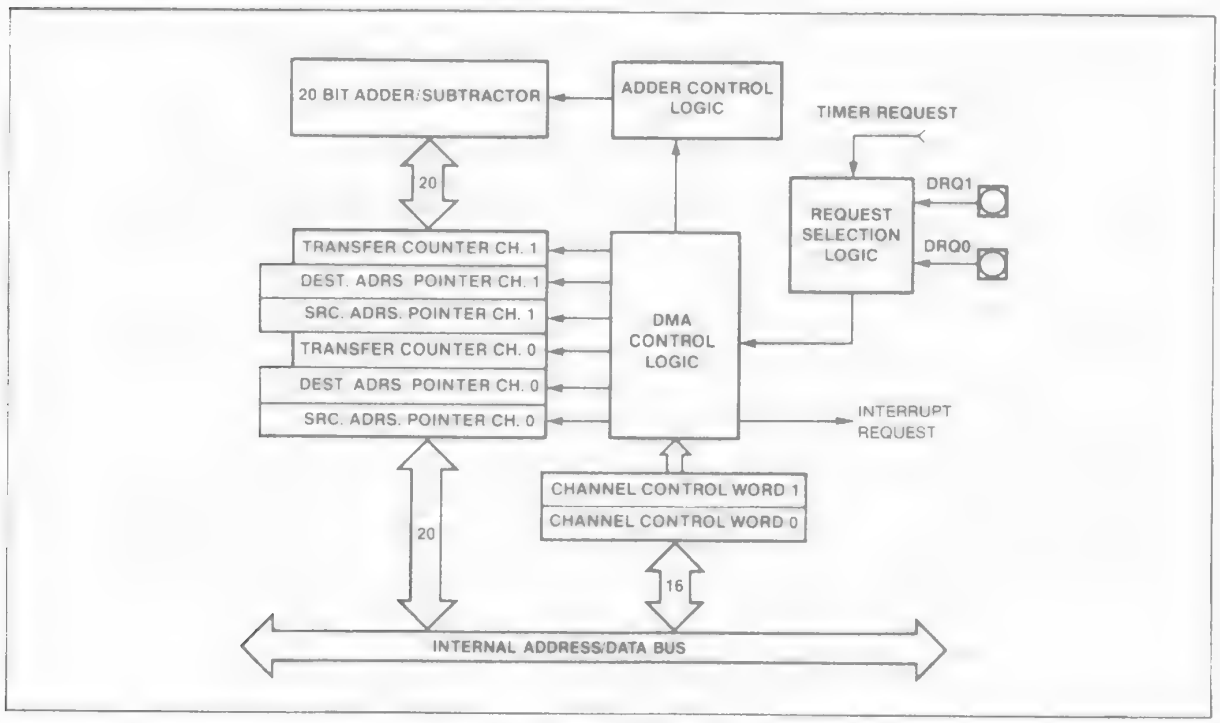

Figure 17. DMA Unit Block Diagram

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15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
M/$\overline{IO}$	DESTINATION DEC	INC	M/$\overline{IO}$	SOURCE DEC	INC	TC	INT	SYN		P	TDRQ	X	CHG/$\overline{NOCHG}$	ST/$\overline{STOP}$	X

X = DON'T CARE.

Figure 18. DMA Control Register

DMA Channel Control Word Register

Each DMA Channel Control Word determines the mode of operation for the particular 80188 DMA channel. This register specifies:

- the mode of synchronization;
- whether interrupts will be generated after the last transfer;
- whether DMA activity will cease after a programmed number of DMA cycles;
- the relative priority of the DMA channel with respect to the other DMA channel;
- whether the source pointer will be incremented, decremented, or maintained constant after each transfer;
- whether the source pointer addresses memory or I/O space;
- whether the destination pointer will be incremented, decremented, or maintained constant after each transfer; and
- whether the destination pointer will address memory or I/O space.

The DMA channel control registers may be changed while the channel is operating. However, any changes made during operation will affect the current DMA transfer.

DMA Control Word Bit Descriptions

ST/$\overline{STOP}$: Start/stop (1/0) Channel.

CHG/$\overline{NOCHG}$: Change/Do not change (1/0) ST/$\overline{STOP}$ bit. If this bit is set when writing to the control word, the ST/$\overline{STOP}$ bit will be programmed by the write to the control word. If this bit is cleared when writing the control word, the ST/$\overline{STOP}$ bit will not be altered. This bit is not stored; it will always be a 0 on read.

INT: Enable Interrupts to CPU on byte count termination.

TC: If set, DMA will terminate when the contents of the Transfer Count register reach zero. The ST/$\overline{STOP}$ bit will also be reset at this point if TC is set. If this bit is cleared, the DMA unit will decrement the transfer count register for each DMA cycle, but the DMA transfer will not stop when the contents of the TC register reach zero.

SYN: (2 bits)
- 00 No synchronization.
  NOTE: The ST bit will be cleared automatically when the contents of the TC register reach zero regardless of the state of the TC bit.
- 01 Source synchronization.
- 10 Destination synchronization.
- 11 Unused.

SOURCE:INC Increment source pointer by 1 after each transfer.

M/$\overline{IO}$ Source pointer is in M/IO space (1/0).

DEC Decrement source pointer by 1 after each transfer.

DEST: INC Increment destination pointer by 1 after each transfer.

M/$\overline{IO}$ Destination pointer is in M/IO space (1/0).

DEC Decrement destination pointer by 1 after each transfer.

P Channel priority—relative to other channel.
- 0 low priority.
- 1 high priority.

Channels will alternate cycles if both set at same priority level.

TDRQ	0: Disable DMA requests from timer 2.
	1: Enable DMA requests from timer 2.
Bit 3	Bit 3 is not used.

If both INC and DEC are specified for the same pointer, the pointer will remain constant after each cycle.

DMA Destination and Source Pointer Registers

Each DMA channel maintains a 20-bit source and a 20-bit destination pointer. Each of these pointers takes up two full 16-bit registers in the peripheral control block. The lower four bits of the upper register contain the upper four bits of the 20-bit physical address (see Figure 18a). These pointers may be individually incremented or decremented after each transfer. Each pointer may point into either memory or I/O space. Since the DMA channels can perform transfers to or from odd addresses, there is no restriction on values for the pointer registers.

DMA Transfer Count Register

Each DMA channel maintains a 16-bit transfer count register (TC). This register is decremented after every DMA cycle, regardless of the state of the TC bit int he DMA Control Register. If the TC bit in the DMA control word is set or unsynchronized transfers are programmed, DMA activity will terminate when the transfer count register reaches zero.

DMA Requests

Data transfers may be either source or destination synchronized, that is either the source of the data or the destination of the data may request the data transfer. In addition, DMA transfers may be unsynchronized; that is, the transfer will take place continually until the correct number of transfers has occurred. When source or unsynchronized transfers are performed, the DMA channel may begin another transfer immediately after the end of a previous DMA transfer. This allows a complete transfer to take place every 2 bus cycles or eight clock cycles (assuming no wait states). No prefetching occurs when destination synchronization is performed, however. Data will not be fetched from the source address until the destination device signals that it is ready to receive it. When destination synchronized transfers are requested, the DMA controller will relinquish control of the bus after every transfer. If no other bus activity is initiated, another DMA cycle will begin after two processor clocks. This is done to allow the destination device time to remove its request if another transfer is not desired. Since the DMA controller will relinquish the bus, the CPU can initiate a bus cycle. As a result, a complete bus cycle will often be inserted between destination synchronized transfers. These lead to the maximum DMA transfer rates shown in Table 14.

Table 14. Maximum DMA Transfer Rates

Type of Synchronization Selected	CPU Running	CPU Halted
Unsynchronized	1MBytes/sec	1MBytes/sec
Source Synch	1MBytes/sec	1MBytes/sec
Destination Synch	.65MBytes/sec	.75MBytes/sec

HIGHER REGISTER ADDRESS	XXX	XXX	XXX	A19–A16
LOWER REGISTER ADDRESS	A15–A12	A11–A8	A7–A4	A3–A0

15 0

XXX = DON'T CARE

Figure 18a. DMA Memory Pointer Register Format

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DMA Acknowledge

No explicit DMA acknowledge pulse is provided. Since both source and destination pointers are maintained, a read from a requesting source, or a write to a requesting destination, should be used as the DMA acknowledge signal. Since the chip-select lines can be programmed to be active for a given block of memory or I/O space, and the DMA pointers can be programmed to point to the same given block, a chip-select line could be used to indicate a DMA acknowledge.

DMA Priority

The DMA channels may be programmed such that one channel is always given priority over the other, or they may be programmed such as to alternate cycles when both have DMA requests pending. DMA cycles always have priority over internal CPU cycles except between locked memory accesses or word accesses the odd memory locations; however, an external bus hold takes priority over an internal DMA cycle. Because an interrupt request cannot suspend a DMA operation and the CPU cannot access memory during a DMA cycle, interrupt latency time will suffer during sequences of continuous DMA cycles. An NMI request, however, will cause all internal DMA activity to halt. This allows the CPU to quickly respond to the NMI request.

DMA Programming

DMA cycles will occur whenever the ST/STOP bit of the Control Register is set. If synchronized transfers are programmed, a DRQ must also have been generated. Therefore, the source and destination transfer pointers, and the transfer count register (if used) must be programmed before this bit is set.

Each DMA register may be modified while the channel is operating. If the CHG/NOCHG bit is cleared when the control register is written, the ST/STOP bit of the control register will not be modified by the write. If multiple channel registers are modified, it is recommended that a LOCKED string transfer be used to prevent a DMA transfer from occurring between updates to the channel registers.

DMA Channels and Reset

Upon RESET, the DMA channels will perform the following actions:

- The Start/Stop bit for each channel will be reset to STOP.
- Any transfer in progress is aborted.

TIMERS

The 80188 provides three internal 16-bit programmable timers (see Figure 19). Two of these are highly flexible and are connected to four external pins (2 per timer). They can be used to count external events, time external events, generate nonrepetitive waveforms, etc. The third timer is not connected to any external pins, and is useful for real-time coding and time delay applications. In addition, this third timer can be used as a prescaler to the other two, or as a DMA request source.

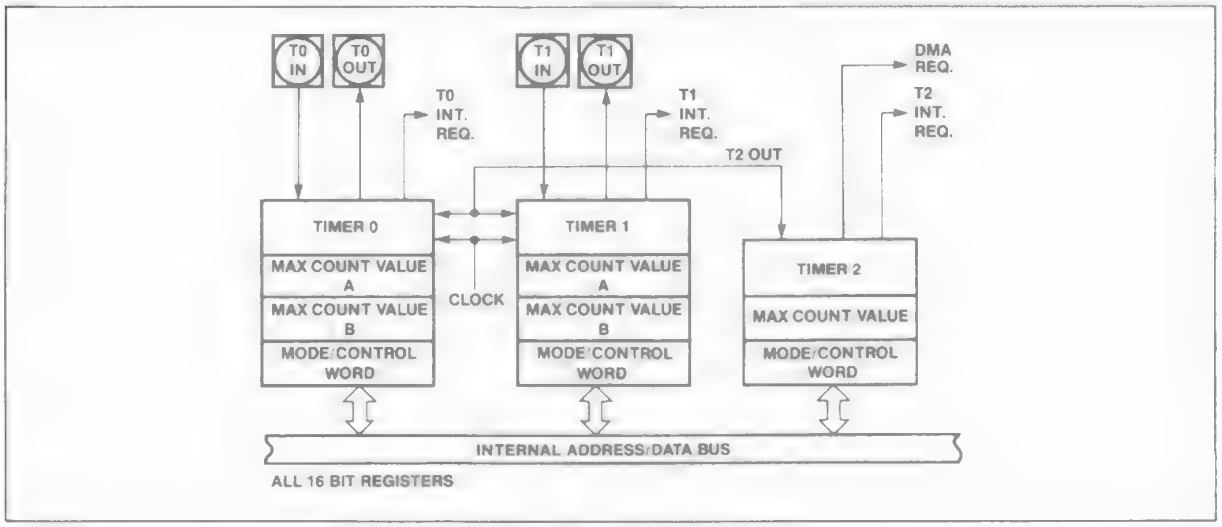

Figure 19. Timer Block Diagram

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Timer Operation

The timers are controlled by 11 16-bit registers in the internal peripheral control block. The configuration of these registers is shown in Table 15. The count register contains the current value of the timer. It can be read or written at any time independent of whether the timer is running or not. The value of this register will be incremented for each timer event. Each of the timers is equipped with a MAX COUNT register, which defines the maximum count the timer will reach. After reaching the MAX COUNT register value, the timer count value will reset to zero during that same clock, i.e., the maximum count value is never stored in the count register itself. Timers 0 and 1 are, in addition, equipped with a second MAX COUNT register, which enables the timers to alternate their count between two different MAX COUNT values programmed by the user. If a single MAX COUNT register is used, the timer output pin will switch LOW for a single clock, 2 clocks after the maximum count value has been reached. In the dual MAX COUNT register mode, the output pin will indicate which MAX COUNT register is currently in use, thus allowing nearly complete freedom in selecting waveform duty cycles. For the timers with two MAX COUNT registers, the RIU bit in the control register determines which is used for the comparison.

Each timer gets serviced every fourth CPU-clock cycle, and thus can operate at speeds up to one-quarter the internal clock frequency (one-eighth the crystal rate). External clocking of the timers may be done at up to a rate of one-quarter of the internal CPU-clock rate (2 MHz for an 8 MHz CPU clock). Due to internal synchronization and pipelining of the timer circuitry, a timer output may take up to 6 clocks to respond to any individual clock or gate input.

Since the count registers and the maximum count registers are all 16 bits wide, 16 bits of resolution are provided. Any Read or Write access to the timers will add one wait state to the minimum four-clock bus cycle, however. This is needed to synchronize and coordinate the internal data flows between the internal timers and the internal bus.

The timers have several programmable options.

- All three timers can be set to halt or continue on a terminal count.
- Timers 0 and 1 can select between internal and external clocks, alternate between MAX COUNT registers and be set to retrigger on external events.
- The timers may be programmed to cause an interrupt on terminal count.

These options are selectable via the timer mode/control word.

Timer Mode/Control Register

The mode/control register (see Figure 20) allows the user to program the specific mode of operation or check the current programmed status for any of the three integrated timers.

Table 15. Timer Control Block Format

Register Name	Register Offset		
	Tmr. 0	Tmr. 1	Tmr. 2
Mode/Control Word	56H	5EH	66H
Max Count B	54H	5CH	not present
Max Count A	52H	5AH	62H
Count Register	50H	58H	60H

Figure 20. Timer Mode/Control Register

ALT:
The ALT bit determines which of two MAX COUNT registers is used for count comparison. If ALT = 0, register A for that timer is always used, while if ALT = 1, the comparison will alternate between register A and register B when each maximum count is reached. This alternation allows the user to change one MAX COUNT register while the other is being used, and thus provides a method of generating non-repetitive waveforms. Square waves and pulse outputs of any duty cycle are a subset of available signals obtained by not changing the final count registers. The ALT bit also determines the function of the timer output pin. If ALT is zero, the output pin will go LOW for one clock, the clock after the maximum count is reached. If ALT is one, the output pin will reflect the current MAX COUNT register being used (0/1 for B/A).

CONT:
Setting the CONT bit causes the associated timer to run continuously, while resetting it causes the timer to halt upon maximum count. If CONT = 0 and ALT =1, the timer will count to the MAX COUNT register A value, reset, count to the register B value, reset, and halt.

EXT:
The external bit selects between internal and external clocking for the timer. The external signal may be asynchronous with respect to the 80188 clock. If this bit is set, the timer will count LOW-to-HIGH transitions on the input pin. If cleared, it will count an internal clock while using the input pin for control. In this mode, the function of the external pin is defined by the RTG bit. The maximum input to output transition latency time may be as much as 6 clocks. However, clock inputs may be pipelined as closely together as every 4 clocks without losing clock pulses.

P:
The prescaler bit is ignored unless internal clocking has been selected (EXT = 0). If the P bit is a zero, the timer will count at one-fourth the internal CPU clock rate. If the P bit is a one, the output of timer 2 will be used as a clock for the timer. Note that the user must initialize and start timer 2 to obtain the prescaled clock.

RTG:
Retrigger bit is only active for internal clocking (EXT = 0). In this case it determines the control function provided by the input pin.

If RTG = 0, the input level gates the internal clock on and off. If the input pin is HIGH, the timer will count; if the input pin is LOW, the timer will hold its value. As indicated previously, the input signal may be asynchronous with respect to the 80188 clock.

When RTG = 1, the input pin detects LOW-to-HIGH transitions. The first such transition starts the timer running, clearing the timer value to zero on the first clock, and then incrementing thereafter. Further transitions on the input pin will again reset the timer to zero, from which it will start counting up again. If CONT = 0, when the timer has reached maximum count, the EN bit will be cleared, inhibiting further timer activity.

EN:
The enable bit provides programmer control over the timer's RUN/HALT status. When set, the timer is enabled to increment subject to the input pin constraints in the internal clock mode (discussed previously). When cleared, the timer will be inhibited from counting. All input pin transitions during the time EN is zero will be ignored. If CONT is zero, the EN bit is automatically cleared upon maximum count.

INH:
The inhibit bit allows for selective updating of the enable (EN) bit. If INH is a one during the write to the mode/control word, then the state of the EN bit will be modified by the write. If INH is a zero during the write, the EN bit will be unaffected by the operation. This bit is not stored; it will always be a 0 on a read.

INT:
When set, the INT bit enables interrupts from the timer, which will be generated on every terminal count. If the timer is configured in dual MAX COUNT register mode, an interrupt will be generated each time the value in MAX COUNT register A is reached, and each time the value in MAX COUNT register B is reached. If this enable bit is cleared after the interrupt request has been generated, but before a pending interrupt is serviced, the interrupt request will still be in force. (The request is latched in the Interrupt Controller.)

MC:
The Maximum Count bit is set whenever the timer reaches its final maximum count value. If the timer is configured in dual MAX COUNT register mode, this bit will be set each time the value in MAX COUNT register A is reached, and each time the value in MAX COUNT register B is reached. This bit is set regardless of the timer's interrupt-enable bit. The MC bit gives the user the ability to monitor timer status through software instead of through interrupts. Programmer intervention is required to clear this bit.

RIU:
The Register In Use bit indicates which MAX COUNT register is currently being used for comparison to the timer count value. A zero value indicates register A. The RIU bit cannot be written, i.e., its value is not affected when the control register is written. It is always cleared when the ALT bit is zero.

Not all mode bits are provided for timer 2. Certain bits are hardwired as indicated below:

ALT = 0, EXT = 0, P = 0, RTG = 0, RIU = 0

Count Registers

Each of the three timers has a 16-bit count register. The current contents of this register may be read or written by the processor at any time. If the register is written into while the timer is counting, the new value will take effect in the current count cycle.

Max Count Registers

Timers 0 and 1 have two MAX COUNT registers, while timer 2 has a single MAX COUNT register. These contain the number of events the timer will count. In timers 0 and 1, the MAX COUNT register used can alternate between the two max count values whenever the current maximum count is reached. The condition which causes a timer to reset is equivalent between the current count value and the max count being used. This means that if the count is changed to be above the max count value, or if the max count value is changed to be below the current value, the timer will not reset to zero, but rather will count to its maximum value, "wrap around" to zero, then count until the max count is reached.

Timers and Reset

Upon RESET, the Timers will perform the following actions:

- All EN (Enable) bits are reset preventing timer counting.
- All SEL (Select) bits are reset to zero. This selects MAX COUNT register A, resulting in the Timer Out pins going HIGH upon RESET.

INTERRUPT CONTROLLER

The 80188 can receive interrupts from a number of sources, both internal and external. The internal interrupt controller serves to merge these requests on a priority basis, for individual service by the CPU.

Internal interrupt sources (Timers and DMA channels) can be disabled by their own control registers or by mask bits within the interrupt controller. The 80188 interrupt controller has its own control registers that set the mode of operation for the controller.

The interrupt controller will resolve priority among requests that are pending simultaneously. Nesting is provided so interrupt service routines for lower priority interrupts may themselves be interrupted by higher priority interrupts. A block diagram of the interrupt controller is shown in Figure 21.

The interrupt controller has a special iRMX 86 compatibility mode that allows the use of the 80188 within the iRMX 86 operating system interrupt structure. The controller is set in this mode by setting bit 14 in the peripheral control block relocation register (see iRMX 86 Compatibility Mode section). In this mode, the internal 80188 interrupt controller functions as a "slave" controller to an external "master" controller. Special initialization software must be included to properly set up the 80188 interrupt controller in iRMX 86 mode.

NON-iRMX MODE OPERATION

Interrupt Controller External Interface

For external interrupt sources, five dedicated pins are provided. One of these pins is dedicated to NMI, non-maskable interrupt. This is typically used for power-fail interrupts, etc. The other four pins may function either as four interrupt input lines with internally generated interrupt vectors, as an interrupt line and an interrupt acknowledge line (called the "cascade mode") along with two other input lines with internally generated interrupt vectors, or as two interrupt input lines and two dedicated interrupt acknowledge ouput lines. When the interrupt lines are configured in cascade mode, the 80188 interrupt controller will not generate internal interrupt vectors.

External sources in the cascade mode use externally generated interrupt vectors. When an interrupt is acknowledged, two $\overline{\text{INTA}}$ cycles are initiated and the vector is read into the 80188 on the second cycle. The capability to interface to external 8259A programmable interrupt controllers is thus provided when the inputs are configured in cascade mode.

Interrupt Controller Modes of Operation

The basic modes of operation of the interrupt controller in non-iRMX mode are similar to the 8259A. The interrupt controller responds identically to internal interrupts in all three modes: the difference is only in the interpretation of function of the four external interrupt pins. The interrupt controller is set into one of these three modes by programming the correct bits in the INT0 and INT1 control registers. The modes of interrupt controller operation are as follows:

Fully Nested Mode

When in the fully nested mode four pins are used as direct interrupt requests. The vectors for these four inputs are generated internally. An in-service bit is provided for every interrupt source. If a lower-priority device requests an interrupt while the in-service bit (IS) is set, no interrupt will be generated by the interrupt controller. In addition, if another interrupt request occurs from the same interrupt source while the inservice bit is set, no interrupt will be generated by the interrupt controller. This allows interrupt service routines to operate with interrupts enabled without being themselves interrupted by lower-priority interrupts. Since interrupts are enabled, higher-priority interrupts will be serviced.

When a service routine is completed, the proper IS bit must be reset by writing the proper pattern to the EOI register. This is required to allow subsequent interrupts from this interrupt source and to allow servicing of lower-priority interrupts. An EOI command is issued at the end of the service routine just before the issuance of the return from interrupt instruction. If the fully nested structure has been upheld, the next highest-priority source with its IS bit set is then serviced.

Cascade Mode

The 80188 has four interrupt pins and two of them have dual functions. In the fully nested mode the four pins are used as direct interrupt inputs and the corresponding vectors are generated internally. In the cascade mode, the four pins are configured into interrupt input-dedicated acknowledge signal pairs. The interconnection is shown in Figure 22. INT0 is an interrupt input interfaced to an 8259A, while INT2/$\overline{\text{INTA0}}$ serves as the dedicated interrupt acknowledge signal to that peripheral. The same is true for INT1 and INT3/$\overline{\text{INTA1}}$. Each pair can selectively be placed in the cascade or non-cascade mode by programming the proper value into INT0 and INT1 control registers. The use of the dedicated acknowledge signals eliminates the need for the use of external logic to generate $\overline{\text{INTA}}$ and device select signals.

The primary cascade mode allows the capability to serve up to 128 external interrupt sources through the use of external master and slave 8259As. Three levels of priority are created, requiring priority resolution in the 80188 interrupt controller, the master 8259As, and the slave 8259As. If an external interrupt is serviced, one IS bit is set at each of these levels. When the interrupt service routine is completed, up to three end-of-interrupt commands must be issued by the programmer.

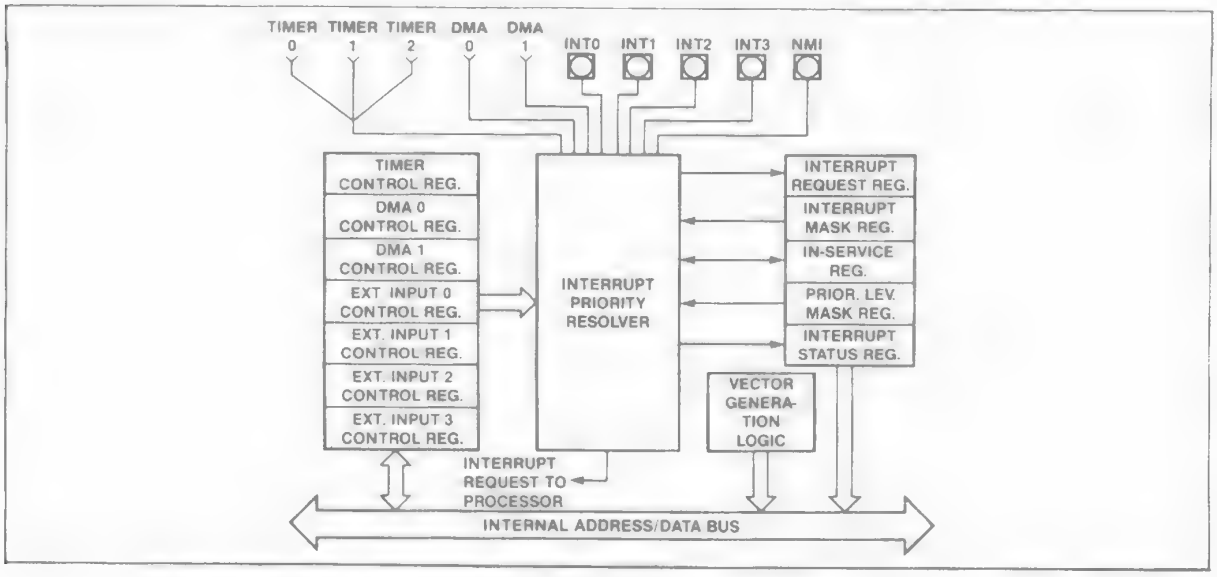

Figure 21. Interrupt Controller Block Diagram

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Special Fully Nested Mode
This mode is entered by setting the SFNM bit in INT0 or INT1 control register. It enables complete nestability with external 8259A masters. Normally, an interrupt request from an interrupt source will not be recognized unless the in-service bit for that source is reset. If more than one interrupt source is connected to an external interrupt controller, all of the interrupts will be funneled through the same 80188 interrupt request pin. As a result, if the external interrupt controller receives a higher-priority interrupt, its interrupt will not be recognized by the 80188 controller until the 80188 in-service bit is reset. In special fully nested mode, the 80188 interrupt controller will allow interrupts from an external pin regardless of the state of the in-service bit for an interrupt source in order to allow multiple interrupts from a single pin. An in-service bit will continue to be set, however, to inhibit interrupts from other lower-priority 80188 interrupt sources.

Special procedures should be followed when resetting IS bits at the end of interrupt service routines. Software polling of the external master's IS register is required to determine if there is more than one bit set. If so, the IS bit in the 80188 remains active and the next interrupt service routine is entered.

Operation in a Polled Environment

The controller may be used in a polled mode if interrupts are undesirable. When polling, the processor disables interrupts and then polls the interrupt controller whenever it is convenient. Polling the interrupt controller is accomplished by reading the Poll Word (Figure 31). Bit 15 in the poll word indicates to the processor that an interrupt of high enought priority is requesting service. Bits 0-4 indicate to the processor the type vector of the highest-priority source requesting service. Reading the Poll Word causes the In-Service bit of the highest-priority source to be set.

It is desirable to be able to read the Poll Word information without guaranteeing service of any pending interrupt, i.e., not set the indicated in-service bit. The 80188 provides a Poll Status Word in addition to the conventional Poll Word to allow this to be done. Poll Word information is duplicated in the Poll Status Word, but reading the Poll Status Word does not set the associated in-service bit. These words are located in two adjacent memory locations in the register file.

Non-iRMX Mode Features

Programmable Priority
The user can program the interrupt sources into any of eight different priority levels. The programming is done by placing a 3-bit priority level (0–7) in the control register of each interrupt source. (A source with a priority level of 4 has higher priority over all priority levels from 5 to 7. Priority registers containing values lower than 4 have greater priority.) All interrupt sources have preprogrammed default priority levels (see Table 4).

If two requests with the same programmed priority level are pending at once, the priority ordering scheme shown in Table 4 is used. If the serviced interrupt routine reenables interrupts, it allows other requests to be serviced.

End-of-Interrupt Command
The end-of-interrupt (EOI) command is used by the programmer to reset the In-Service (IS) bit when an interrupt service routine is completed. The EOI command is issued by writing the proper pattern to the EOI register. There are two types of EOI commands, specific and nonspecific. The nonspecific command does not specify which IS bit is reset. When issued, the interrupt controller automatically resets the IS bit of the highest priority source with an active service routine. A specific EOI command requires that the programmer send the interrupt vector type to the interrupt controller indicating which source's IS bit is to be reset. This command is used when the fully nested structure has been disturbed or the highest priority IS bit that was set does not belong to the service routine in progress.

Trigger Mode
The four external interrupt pins can be programmed in either edge- or level-trigger mode. The control register for each external source has a level-trigger mode (LTM) bit. All interrupt inputs are active HIGH. In the edge sense mode or the level-trigger mode, the interrupt request must remain active (HIGH) until the interrupt request is acknowledged by the 80188 CPU. In the edge-sense mode, if the level remains high after the interrupt is acknowledged, the input is disabled and no further requests will be generated. The input level must go LOW for at least one clock cycle to reenable the input. In the level-trigger mode, no such provision is made: holding the interrupt input HIGH will cause continuous interrupt requests.

Interrupt Vectoring
The 80188 Interrupt Controller will generate interrupt vectors for the integrated DMA channels and the integrated Timers. In addition, the Interrupt Controller will generate interrupt vectors for the external interrupt lines if they are not configured in Cascade or Special Fully Nested Mode. The interrupt vectors generated are fixed and cannot be changed (see Table 4).

Interrupt Controller Registers

The Interrupt Controller register model is shown in Figure 23. It contains 15 registers. All registers can both be read or written unless specified otherwise.

In-Service Register
This register can be read from or written into. The format is shown in Figure 24. It contains the In-Service bit for each of the interrupt sources. The In-Service bit is set to indicate that a source's service routine is in progress. When an In-Service bit is set, the interrupt controller will not generate interrupts to the CPU when it receives interrupt requests from devices with a lower programmed priority level. The TMR bit is the In-Service bit for all three timers; the D0 and D1 bits are the In-Service bits for the two DMA channels; the I0–I3 are the In-Service bits for the external interrupt pins. The IS bit is set when the processor acknowledges an interrupt request either by an interrupt acknowledge or by reading the poll register. The IS bit is reset at the end of the interrupt service routine by an end-of-interrupt command issued by the CPU.

Interrupt Request Register
The internal interrupt sources have interrupt request bits inside the interrupt controller. The format of this register is shown in Figure 24. A read from this register yields the status of these bits. The TMR bit is the logical OR of all timer interrupt requests. D0 and D1 are the interrupt request bits for the DMA channels.

The state of the external interrupt input pins is also indicated. The state of the external interrupt pins is not a stored condition inside the interrupt controller, therefore the external interrupt bits cannot be written. The external interrupt request bits show exactly when an interrupt request is given to the interrupt controller, so if edge-triggered mode is selected, the bit in the register will be HIGH only after an inactive-to-active transition. For internal interrupt sources, the register bits are set when a request arrives and are reset when the processor acknowledges the requests.

Mask Register
This is a 16-bit register that contains a mask bit for each interrupt source. The format for this register is shown in Figure 24. A one in a bit position corresponding to a particular source serves to mask the source from generating interrupts. These mask bits are the exact same bits which are used in the individual control registers; programming a mask bit using the mask register will also change this bit in the individual control registers, and vice versa.

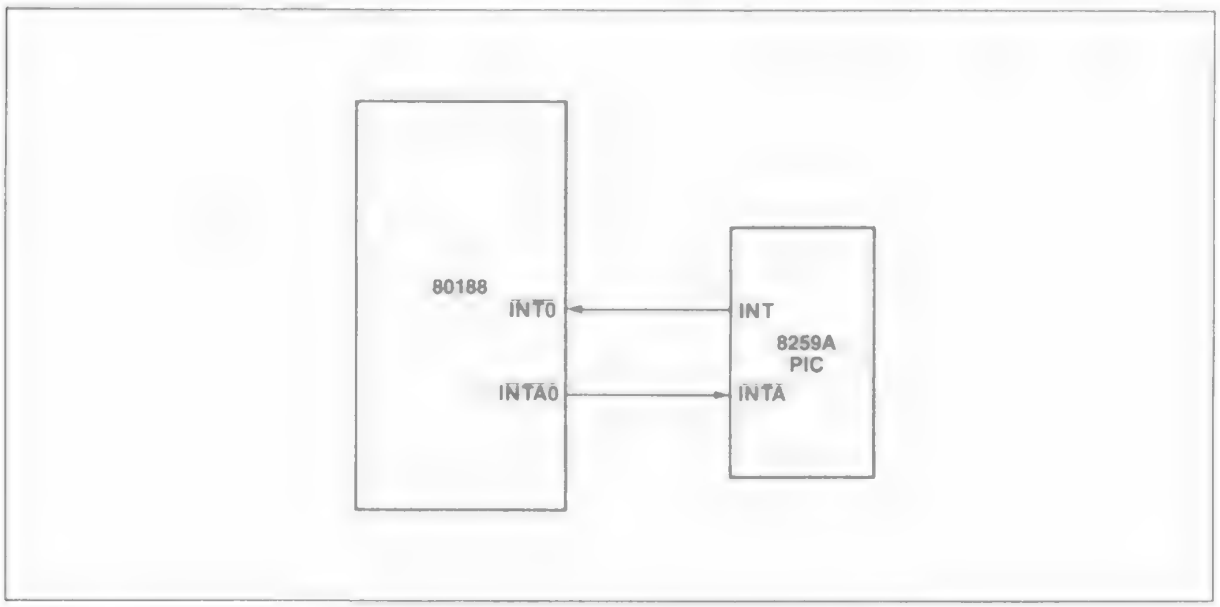

Figure 22. Cascade Mode Interrupt Connection

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	OFFSET
INT3 CONTROL REGISTER	[illegible]H
INT2 CONTROL REGISTER	3CH
INT1 CONTROL REGISTER	[illegible]
INT0 CONTROL REGISTER	38H
DMA 1 CONTROL REGISTER	36H
DMA 0 CONTROL REGISTER	34H
TIMER CONTROL REGISTER	32H
INTERRUPT STATUS REGISTER	30H
INTERRUPT REQUEST REGISTER	2EH
IN-SERVICE REGISTER	2CH
PRIORITY MASK REGISTER	[illegible]
MASK REGISTER	[illegible]
POLL STATUS REGISTER	[illegible]
POLL REGISTER	24H
EOI REGISTER	22H

Figure 23. Interrupt Controller Registers (Non-iRMX 86 Mode)

Priority Mask Register

This register is used to mask all interrupts below particular interrupt priority levels. The format of this register is shown in Figure 25. The code in the lower three bits of this register inhibits interrupts of priority lower (a higher priority number) than the code specified. For example, 100 written into this register masks interrupts of level five (101), six (110), and seven (111). The register is reset to seven (111) upon RESET so all interrupts are unmasked.

Interrupt Status Register

This register contains general interrupt controller status information. The format of this register is shown in Figure 26. The bits in the status register have the following functions:

DHLT: DMA Halt Transfer; setting this bit halts all DMA transfers. It is automatically set whenever a non-maskable interrupt occurs, and it is reset when an IRET instruction is executed. The purpose of this bit is to allow prompt service of all non-maskable interrupts. This bit may also be set by the CPU.

IRTx: These three bits represent the individual timer interrupt request bits. These bits are used to differentiate the timer interrupts, since the timer IR bit in the interrupt request register is the "OR" function of all timer interrupt requests. Note that setting any one of these three bits initiates an interrupt request to the interrupt controller.

15	14		10	9	[illegible]	7	6	5	4	3	[illegible]	1	0
0	0	• • •	0	0	0	I3	I2	I1	I0	D1	D0	0	TMR

Figure 24. In-Service, Interrupt Request, and Mask Register Formats

15	14		3	2	1	0
0	0	• • • • • • • • •	0	PRM2	PRM1	PRM0

Figure 25. Priority Mask Register Format

15	14		7	6	5	4	[illegible]	2	1	0
DHLT	0	• • • • •	0	0	0	0	0	IRT2	IRT1	IRT0

Figure 26. Interrupt Status Register Format

Timer, DMA 0, 1; Control Registers
These registers are the control words for all the internal interrupt sources. The format for these registers is shown in Figure 27. The three bit positions PR0, PR1, and PR2 represent the programmable priority level of the interrupt source. The MSK bit inhibits interrupt requests from the interrupt source. The MSK bits in the individual control registers are the exact same bits as are in the Mask Register; modifying them in the individual control registers will also modify them in the Mask Register, and vice versa.

INT0–INT3 Control Registers
These registers are the control words for the four external input pins. Figure 28 shows the format of the INT0 and INT1 Control registers; Figure 29 shows the format of the INT2 and INT3 Control registers. In cascade mode or special fully nested mode, the control words for INT2 and INT3 are not used.

The bits in the various control registers are encoded as follows:

PRO-2: Priority programming information. Highest priority = 000, lowest priority = 111.

LTM: Level-trigger mode bit. 1 = level-triggered; 0 = edge-triggered. Interrupt Input levels are active high. In level-triggered mode, an interrupt is generated whenever the external line is high. In edge-triggered mode, an interrupt will be generated only when this level is preceded by an inactive-to-active transition on the line. In both cases, the level must remain active until the interrupt is acknowledged.

MSK: Mask bit, 1 = mask; 0 = nonmask.

C: Cascade mode bit, 1 = cascade; 0 = direct

SFNM: Special fully nested mode bit, 1 = SFNM

EOI Register
The end of the interrupt register is a command register which can only be written into. The format of this register is shown in Figure 30. It initiates an EOI command when written to by the 80188 CPU.

The bits in the EOI register are encoded as follows:

S_X: Encoded information that specifies an interrupt source vector type as shown in Table 4. For example, to reset the In-Service bit for DMA channel 0, these bits should be set to 01010, since the vector type for DMA channel 0 is 10. Note that to reset the single In-Service bit for any of the three timers, the vector type for timer 0 (8) should be written in this register.

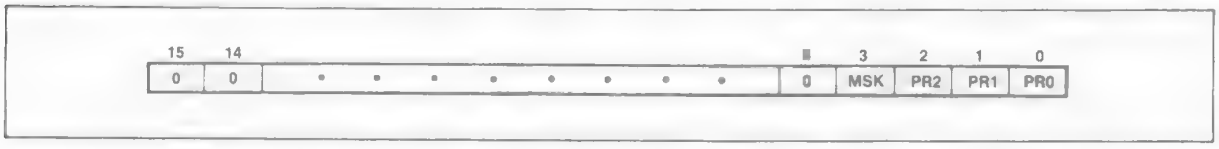

Figure 27. Timer/DMA Control Register Formats

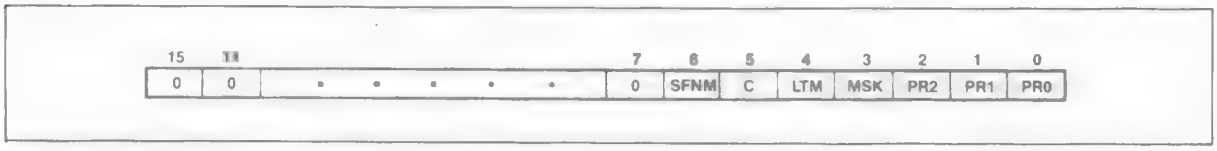

Figure 28. INT0/INT1 Control Register Formats

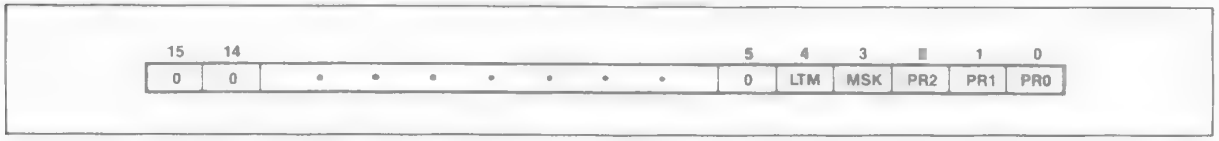

Figure 29. INT2/INT3 Control Register Formats

NSPEC/SPEC: A bit that determines the type of EOI command. Nonspecific = 1, Specific = 0.

Poll and Poll Status Registers

These registers contain polling information. The format of these registers is shown in Figure 31. They can only be read. Reading the Poll register constitutes a software poll. This will set the IS bit of the highest priority pending interrupt. Reading the poll status register will not set the IS bit of the highest priority pending interrupt; only the status of pending interrupts will be provided.

Encoding of the Poll and Poll Status register bits are as follows:

S_x: Encoded information that indicates the vector type of the highest priority interrupting source. Valid only when INTREQ = 1.

INTREQ: This bit determines if an interrupt request is present. Interrupt Request = 1; no Interrupt Request = 0.

iRMX 86 COMPATIBILITY MODE

This mode allows iRMX 86-80188 compatibility. The interrupt model of iRMX 86 requires one master and multiple slave 8259As in cascaded fashion. When iRMX mode is used, the internal 80188 interrupt controller will be used as a slave controller to an external master interrupt controller. The internal 80188 resources will be monitored through the internal interrupt controller, while the external controller functions as the system master interrupt controller.

Upon reset, the 80188 interrupt controller will be in the non-iRMX 86 mode of operation. To set the controller in the iRMX 86 mode, bit 14 of the Relocation Register should be set.

Because of pin limitations caused by the need to interface to an external 8259A master, the internal interrupt controller will no longer accept external inputs. There are however, enough 80188 interrupt controller inputs (internally) to dedicate one to each timer. In this mode, each timer interrupt source has its own mask bit, IS bit, and control word.

The iRMX 86 operating system requires peripherals to be assigned fixed priority levels. This is incompatible with the normal operation of the 80188 interrupt controller. Therefore, the initialization software must program the proper priority levels for each source. The required priority levels for the internal interrupt sources in iRMX mode are shown in Table 16.

Table 16. Internal Source Priority Level

Priority Level	Interrupt Source
0	Timer 0
1	(reserved)
2	DMA 0
3	DMA 1
4	Timer 1
5	Timer 2

These level assignments must remain fixed in the iRMX 86 mode of operation.

iRMX 86 Mode External Interface

The configuration of the 80188 with respect to an external 8259A master is shown in Figure 32. The INT0 input is used as the 80188 CPU interrupt input. INT3 functions as an output to send the 80188 slave-interrupt-request to one of the 8 master-PIC-inputs.

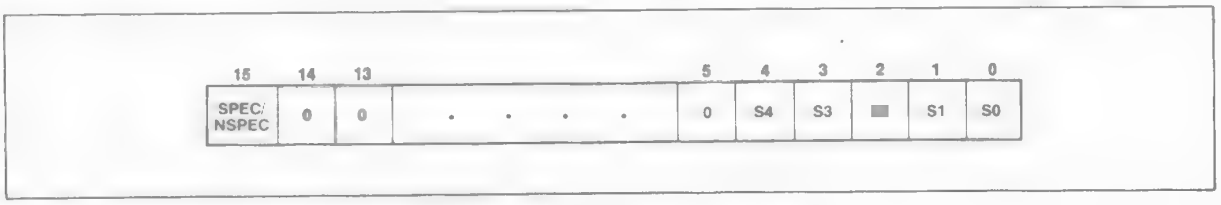

Figure 30. EOI Register Format

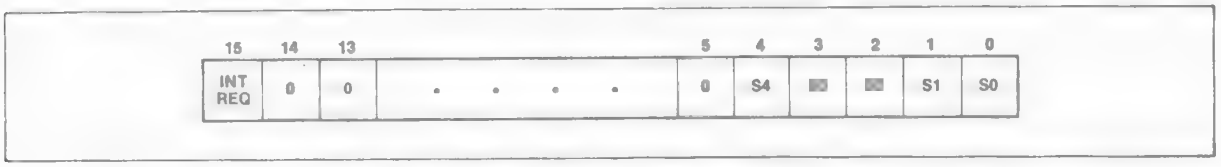

Figure 31. Poll Register Format

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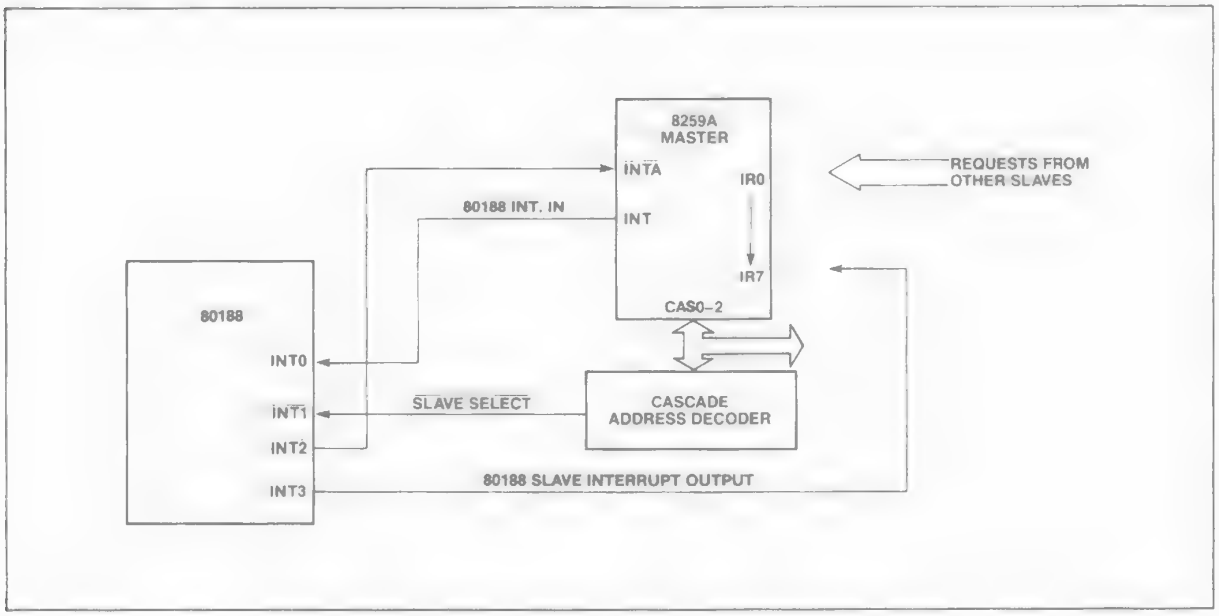

Figure 32. iRMX 86 Interrupt Controller Interconnection

Correct master-slave interface requires decoding of the slave addresses (CAS0–2). Slave 8259As do this internally. Because of pin limitations, the 80188 slave address will have to be decoded externally. $\overline{INT1}$ is used as a slave-select input. Note that the slave vector address is transferred internally, but the READY input must be supplied externally.

$\overline{INT2}$ is used as an acknowledge output, suitable to drive the $\overline{INTA}$ input of an 8259A.

Interrupt Nesting

iRMX 86 mode operation allows nesting of interrupt requests. When an interrupt is acknowledged, the priority logic masks off all priority levels except those with equal or higher priority.

Vector Generation in the iRMX 86 Mode

Vector generation in iRMX mode is exactly like that of an 8259A slave. The interrupt controller generates an 8-bit vector which the CPU multiplies by four and uses as an address into a vector table. The significant five bits of the vector are user-programmable while the lower three bits are generated by the priority logic. These bits represent the encoding of the priority level requesting service. The significant five bits of the vector are programmed by writing to the Interrupt Vector register at offset 20H.

Specific End-of-Interrupt

In iRMX mode the specific EOI command operates to reset an in-service bit of a specific priority. The user supplies a 3-bit priority-level value that points to an in-service bit to be reset. The command is executed by writing the correct value in the Specific EOI register at offset 22H.

Interrupt Controller Registers in the iRMX 86 Mode

All control and command registers are located inside the internal peripheral control block. Figure 33 shows the offsets of these registers.

End-of-Interrupt Register

The end-of-interrupt register is a command register which can only be written. The format of this register is shown in Figure 34. It initiates an EOI command when written by the 80188 CPU.

The bits in the EOI register are encoded as follows:

L_x: Encoded value indicating the priority of the IS bit to be reset.

In-Service Register

This register can be read from or written into. It contains the in-service bit for each of the internal

interrupt sources. The format for this register is shown in Figure 35. Bit positions 2 and 3 correspond to the DMA channels; positions 0, 4, and 5 correspond to the integral timers. The source's IS bit is set when the processor acknowledges its interrupt request.

Interrupt Request Register

This register indicates which internal peripherals have interrupt requests pending. The format of this register is shown in Figure 35. The interrupt request bits are set when a request arrives from an internal source, and are reset when the processor acknowledges the request.

Mask Register

This register contains a mask bit for each interrupt source. The format for this register is shown in Figure 35. If the bit in this register corresponding to a particular interrupt source is set, any interrupts from that source will be masked. These mask bits are exactly the same bits which are used in the individual control registers, i.e., changing the state of a mask bit in this register will also change the state of the mask bit in the individual interrupt control register corresponding to the bit.

Control Registers

These registers are the control words for all the internal interrupt sources. The format of these registers is shown in Figure 36. Each of the timers and both of the DMA channels have their own Control Register.

The bits of the Control Registers are encoded as follows:

pr_x: 3-bit encoded field indicating a priority level for the source; note that each source must be programmed at specified levels.

msk: mask bit for the priority level indicated by pr_x bits.

	OFFSET
LEVEL 5 CONTROL REGISTER (TIMER 2)	3AH
LEVEL 4 CONTROL REGISTER (TIMER 1)	38H
LEVEL 3 CONTROL REGISTER (DMA 1)	[illegible]
LEVEL 2 CONTROL REGISTER (DMA 0)	34H
LEVEL 0 CONTROL REGISTER (TIMER 0)	[illegible]
INTERRUPT STATUS REGISTER	30H
INTERRUPT REQUEST REGISTER	[illegible]EH
IN-SERVICE REGISTER	2CH
PRIORITY-LEVEL MASK REGISTER	2AH
MASK REGISTER	28H
SPECIFIC EOI REGISTER	22H
INTERRUPT VECTOR REGISTER	20H

Figure 33. Interrupt Controller Registers (IRMX 86 Mode)

15	14	13		8	7	6	5	[illegible]	[illegible]	2	1	0
0	0	0	. . . . .	0	0	0	0	0	0	[illegible]	L1	[illegible]

Figure 34. Specific EOI Register Format

15	14	13		8	7	6	5	[illegible]	[illegible]	[illegible]	1	0
0	0	0	. . . . .	0	0	0	[illegible]	[illegible]	D1	D0	0	TMR0

Figure 35. In-Service, Interrupt Request, and Mask Register Format

Interrupt Vector Register
This register provides the upper five bits of the interrupt vector address. The format of this register is shown in Figure 37. The interrupt controller itself provides the lower three bits of the interrupt vector as determined by the priority level of the interrupt request.

The format of the bits in this register is:

t_x: 5-bit field indicating the upper five bits of the vector address.

Priority-Level Mask Register
This register indicates the lowest priority-level interrupt which will be serviced.

The encoding of the bits in this register is:

m_x: 3-bit encoded field indication priority-level value. All levels of lower priority will be masked.

Interrupt Status Register
This register is defined exactly as in non-iRMX mode (see Figure 26).

Interrupt Controller and Reset

Upon RESET, the interrupt controller will perform the following actions:

- All SFNM bits reset to 0, implying Fully Nested Mode.
- All PR bits in the various control registers set to 1. This places all sources at lowest priority (level 111).
- All LTM bits reset to 0, resulting in edge-sense mode.
- All Interrupt Service bits reset to 0.
- All Interrupt Request bits reset to 0.
- All MSK (Interrupt Mask) bits set to 1 (mask).
- All C (Cascade) bits reset to 0 (non-cascade).
- All PRM (Priority Mask) bits set to 1, implying no levels masked.
- Initialized to non-iRMX 86 mode.

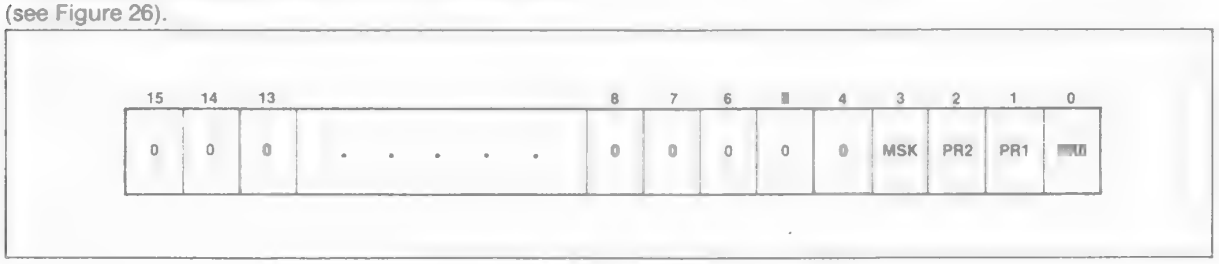

Figure 36. Control Word Format

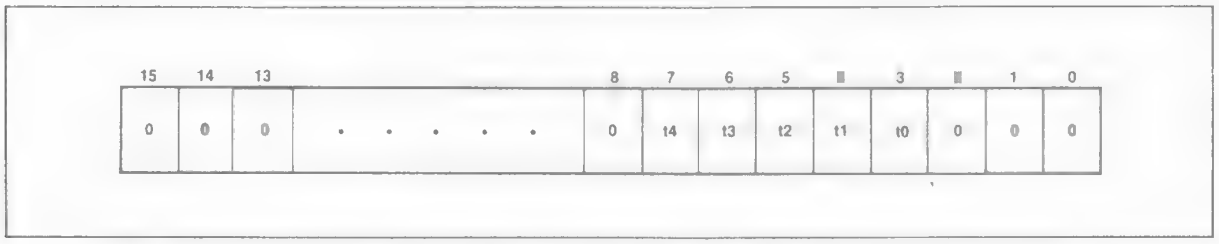

Figure 37. Interrupt Vector Register Format

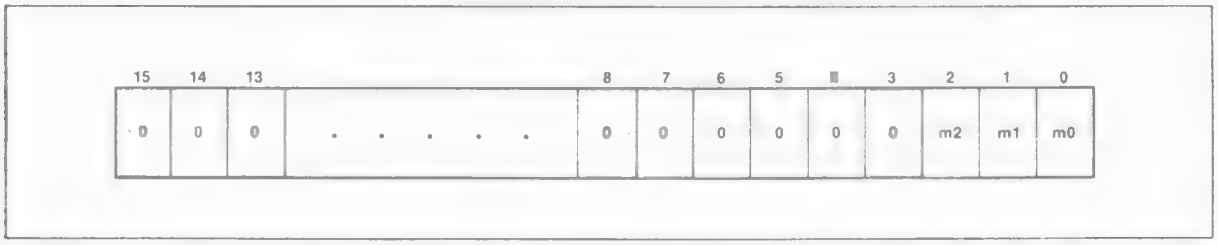

Figure 38. Priority Level Mask Register

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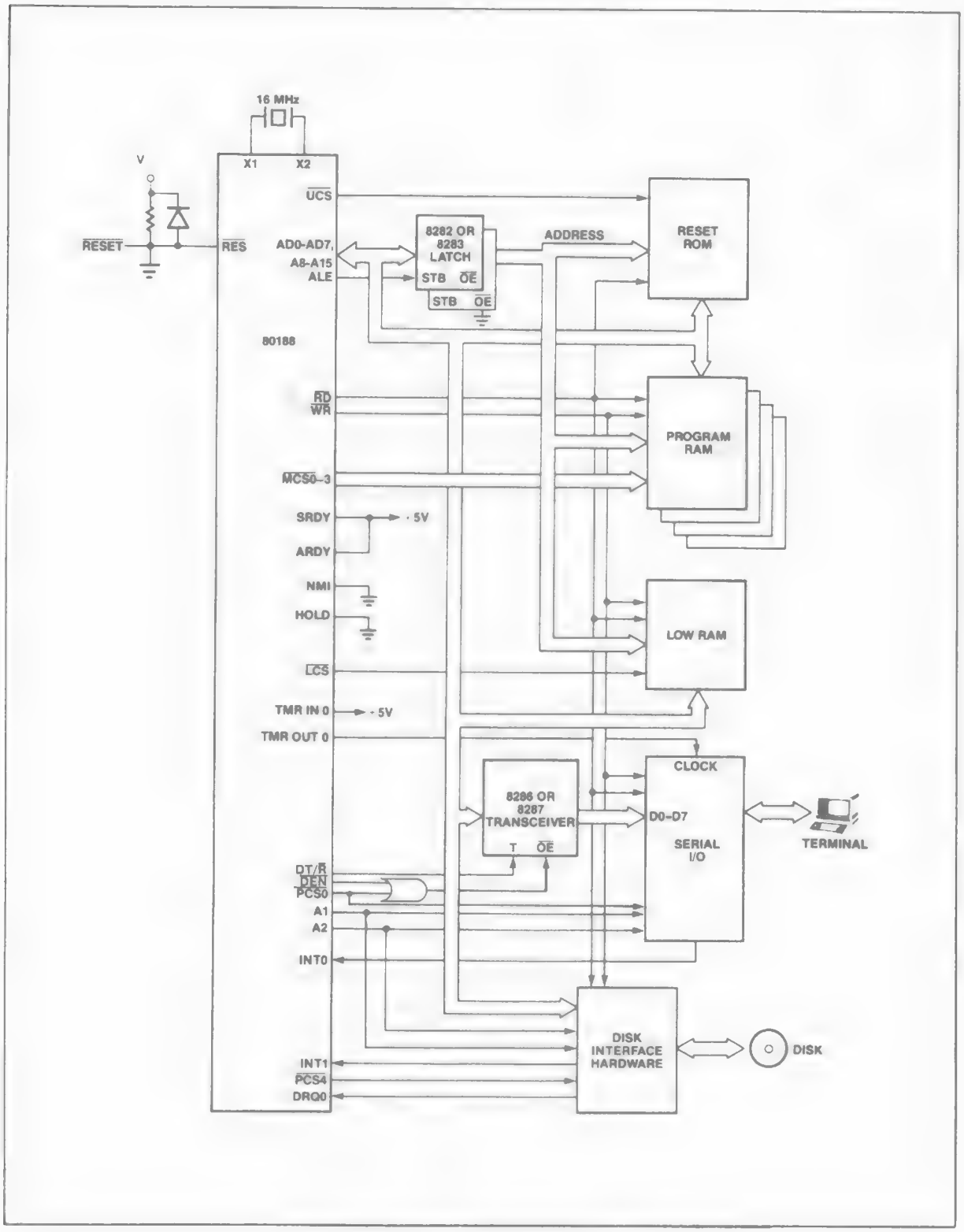

Figure 39. Typical iAPX 188 Computer

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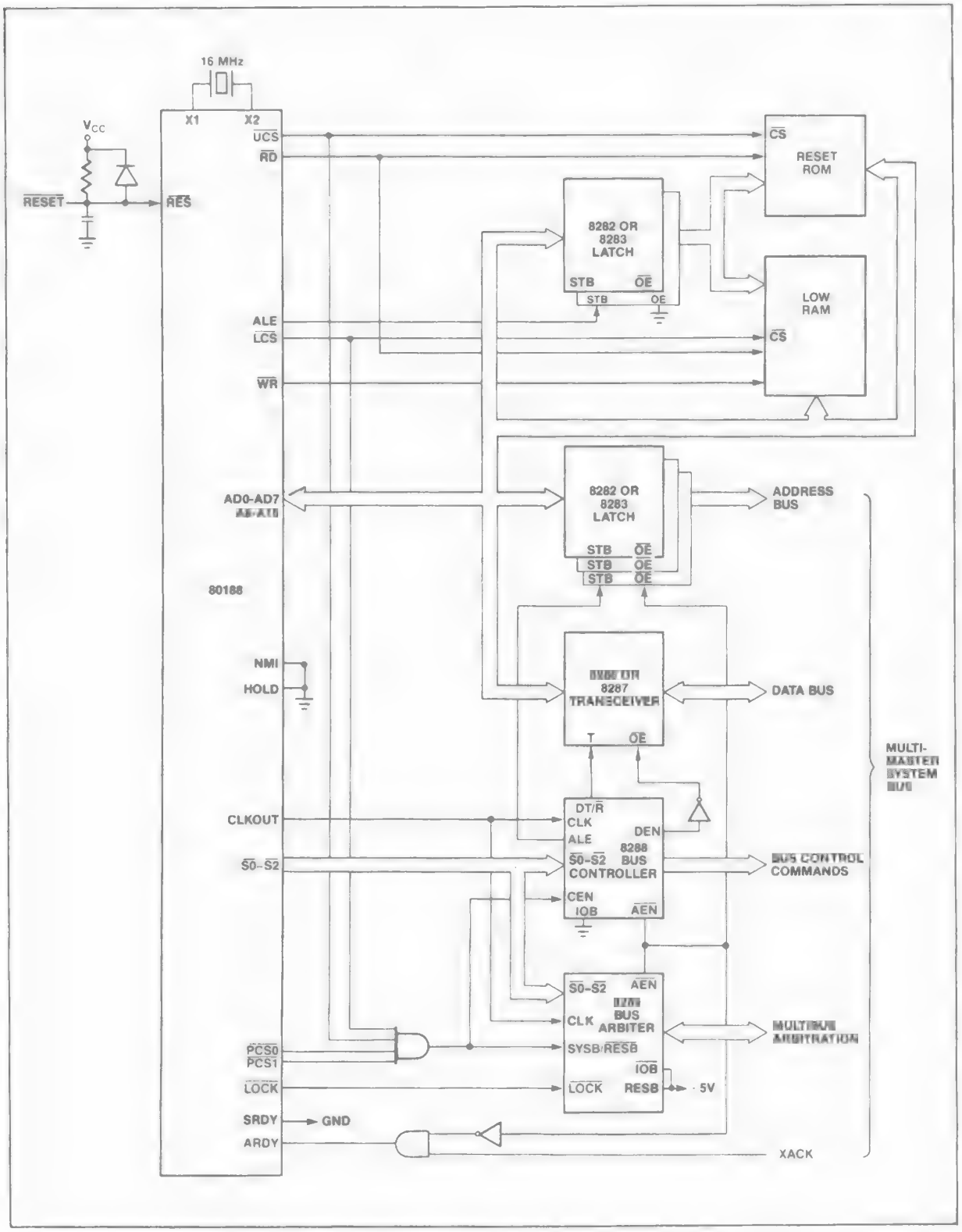

Figure 40. Typical iAPX 188 Multi-Master Bus Interface

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PACKAGE

The 80188 is housed in a 68-pin, leadless JEDEC type A hermetic chip carrier. Figure 41 illustrates the package dimensions.

NOTE: The IDT 3M Textool 68-pin JEDEC Socket is required for ICE™ operation. See Figure 42 for details.

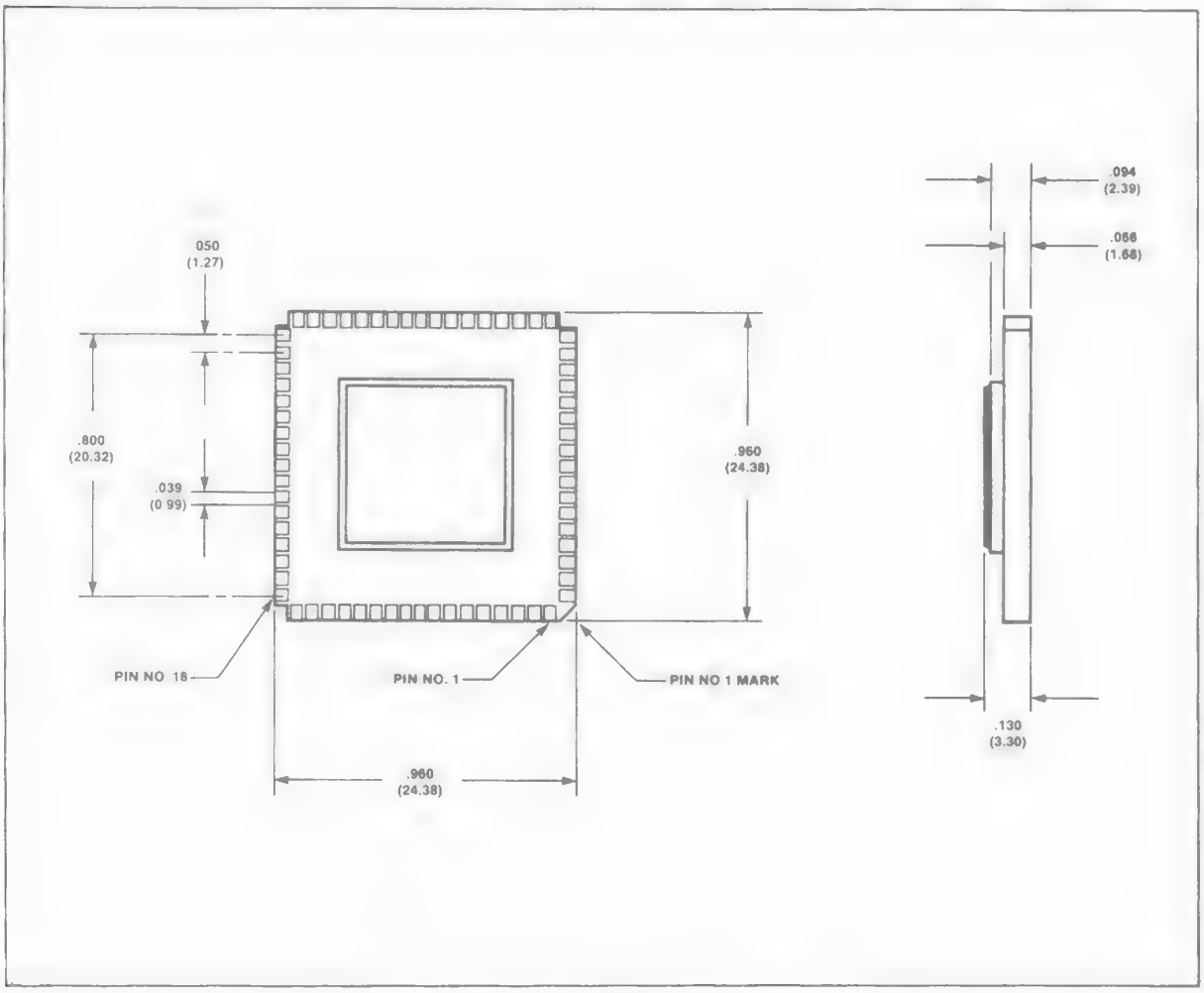

Figure 41. 80188 JEDEC Type A Package

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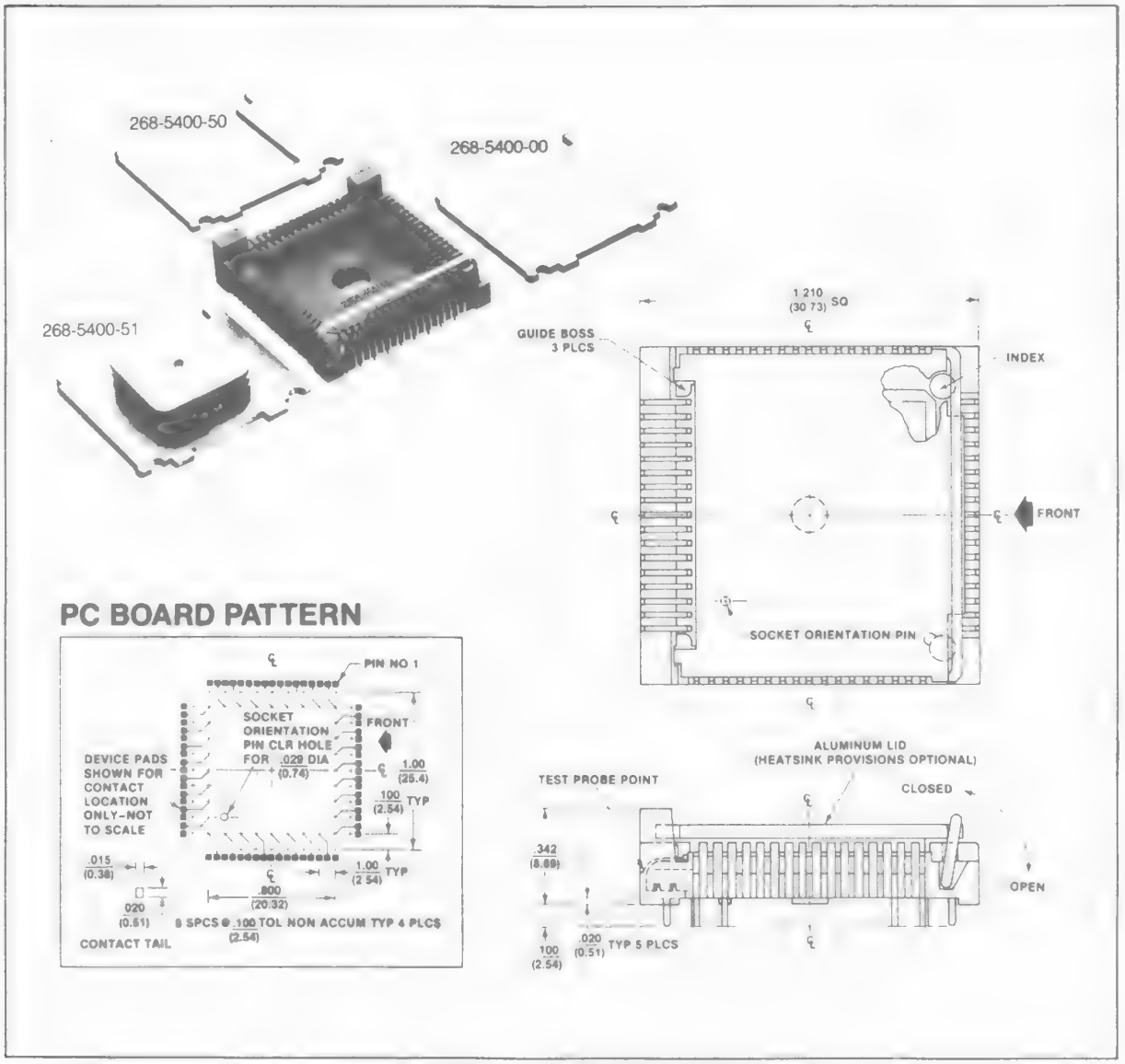

Figure 42. Textool 68 Lead Chip Carrier Socket

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ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage on Any Pin with
Respect to Ground ..... −1.0V to +7V
Power Dissipation ..... 3 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°–70°C, V_{CC} = 5V ±10%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	+0.8	Volts	
V_{IH}	Input High Voltage (All except X1 and $\overline{RES}$)	2.0	V_{CC} + 0.5	Volts	
V_{IH1}	Input High Voltage ($\overline{RES}$)	TBD	V_{CC} + 0.5	Volts	
V_{OL}	Output Low Voltage		0.45	Volts	I_a = 2.5 mA for $\overline{S0}$–$\overline{S2}$ I_a = 2.0 mA for all other outputs
V_{OH}	Output High Voltage		2.4	Volts	I_{oa} = −400 μA
I_{CC}	Power Supply Current		550	mA	T_A = 25°C
I_{LI}	Input Leakage Current		±10	μA	0V < V_{IN} < V_{CC}
I_{LO}	Output Leakage Current		±10	μA	0.45V < V_{OUT} < V_{CC}
V_{CLO}	Clock Output Low		0.6	Volts	I_a = 2.5 mA
V_{CHO}	Clock Output High	4.0		Volts	I_{oa} = −200 μA
V_{CLI}	Clock Input Low Voltage	−0.5	0.6	Volts	
V_{CHI}	Clock Input High Voltage	3.9	V_{CC} + 1.0	Volts	
C_{IN}	Input Capacitance		10	pF	
C_{IO}	I/O Capacitance		20	pF	

PIN TIMINGS

A.C. CHARACTERISTICS (T_A = 0°–70°C, V_{CC} = 5V ± 10%)

80188 Timing Requirements All Timings Measured At 1.5 Volts Unless Otherwise Noted.

Symbol	Parameter	Min.	Max.	Units	Test Conditions
TDVCL	Data in Setup (A/D)	20		ns	
TCLDX	Data in Hold (A/D)	10		ns	
TARYHCH	Asynchronous Ready (AREADY) active setup time*	20		ns	
TARYLCL	AREADY inactive setup time	35		ns	
TCHARYX	AREADY hold time	15		ns	
TSRYCL	Synchronous Ready (SREADY) transition setup time	35		ns	
TCLSRY	SREADY transition hold time	15		ns	
THVCL	HOLD Setup*	25		ns	
TINVCH	INTR, NMI, $\overline{TEST}$, TIMERIN, Setup*	25		ns	
TINVCL	DRQ0, DRQ1, Setup*	25		ns	

*To guarantee recognition at next clock.

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A.C. CHARACTERISTICS (Continued)

80188 Master Interface Timing Responses

Symbol	Parameter	Min.	Max.	Units	Test Conditions
TCLAV	Address Valid Delay	10	44	ns	C_L = 20–200 pF all outputs
TCLAX	Address Hold	10		ns	
TCLAZ	Address Float Delay	TCLAX	35	ns	
TCHCZ	Command Lines Float Delay		45	ns	
TCHCV	Command Lines Valid Delay (after float)		55	ns	
TLHLL	ALE Width	TCLCL-35		ns	
TCHLH	ALE Active Delay		35	ns	
TCHLL	ALE Inactive Delay		35	ns	
TLLAX	Address Hold to ALE Inactive	TCHCL-25		ns	
TCLDV	Data Valid Delay	10	44	ns	
TCLDOX	Data Hold Time	10		ns	
TWHDX	Data Hold after $\overline{WR}$	TCLCL-40		ns	
TCVCTV	Control Active Delay1	10	70	ns	
TCHCTV	Control Active Delay2	10	55	ns	
TCVCTX	Control Inactive Delay	10	55	ns	
TAZRL	Address Float to $\overline{RD}$ Active	0		ns	
TCLRL	$\overline{RD}$ Active Delay	10	70	ns	
TCLRH	$\overline{RD}$ Inactive Delay	10	55	ns	
TRHAV	$\overline{RD}$ Inactive to Address Active	TCLCL-40		ns	
TCLHAV	HLDA Valid Delay	10	50	ns	
TRLRH	$\overline{RD}$ Width	2TCLCL-50		ns	
TWLWH	$\overline{WR}$ Width	2TCLCL-40		ns	
TAVAL	Address Valid to ALE Low	TCLCH-25		ns	
TCHSV	Status Active Delay	10	55	ns	
TCLSH	Status Inactive Delay	10	55	ns	
TCLTMV	Timer Output Delay		60	ns	100 pf max
TCLRO	Reset Delay		60	ns	
TCHQSV	Queue Status Delay		35	ns	

80188 Chip-Select Timing Responses

Symbol	Parameter	Min.	Max.	Units	Test Conditions
TCLCSV	Chip-Select Active Delay		66	ns	
TCXCSX	Chip-Select Hold from Command Inactive	35		ns	
TCHCSX	Chip-Select Inactive Delay	10	35	ns	

A.C. CHARACTERISTICS (Continued)

80188 CLKIN Requirements

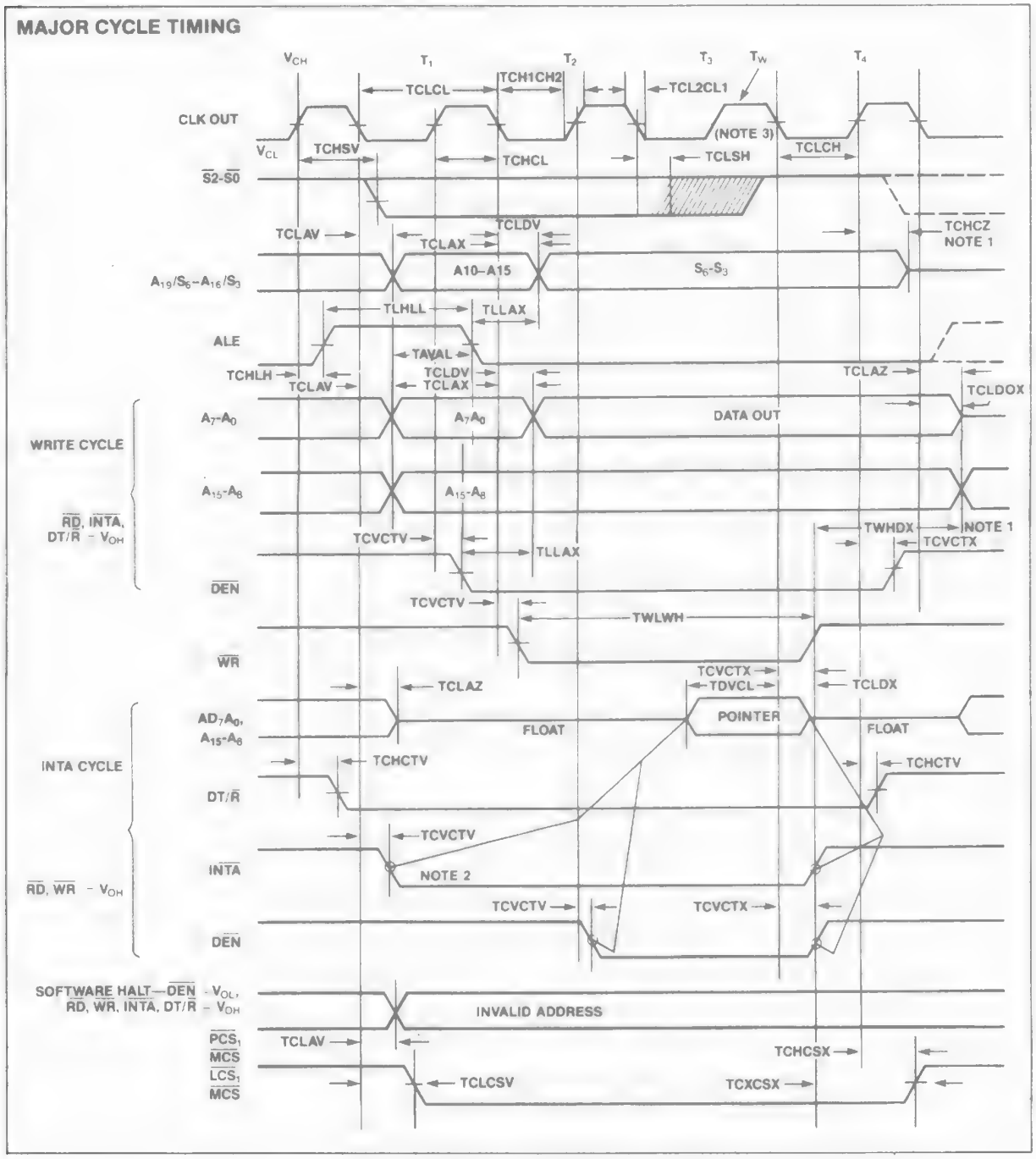
Symbol	Parameter	Min.	Max.	Units	Test Conditions
TCKIN	CLKIN Period	62.5	250	ns	
TCKHL	CLKIN Fall Time		10	ns	3.5 to 1.0 volts
TCKLH	CLKIN Rise Time		10	ns	1.0 to 3.5 volts
TCLCK	CLKIN Low Time	25		ns	1.5 volts
TCHCK	CLKIN High Time	25		ns	1.5 volts

80188 CLKOUT Timing (200 pF load)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
TCICO	CLKIN to CLKOUT Skew		50	ns	
TCLCL	CLKOUT Period	125	500	ns	
TCLCH	CLKOUT Low Time	½ TCLCL-7.5		ns	1.5 volts
TCHCL	CLKOUT High Time	½ TCLCL-7.5		ns	1.5 volts
TCH1CH2	CLKOUT Rise Time		15	ns	1.0 to 3.5 volts
TCL2CL1	CLKOUT Fall Time		15	ns	3.5 to 1.0 volts

WAVEFORMS

MAJOR CYCLE TIMING



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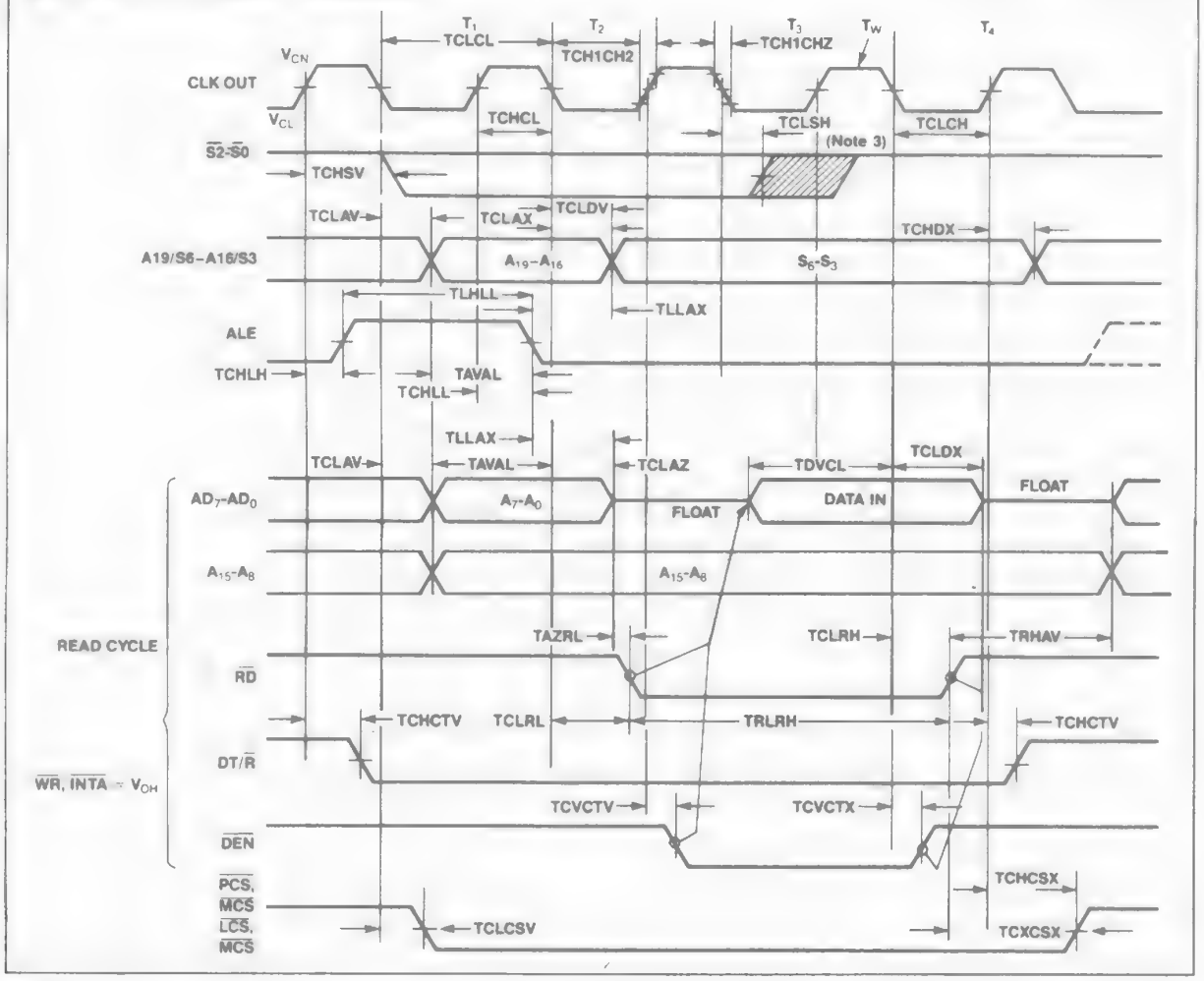
WAVEFORMS (Continued)

MAJOR CYCLE TIMING (Continued)



NOTES
1. Following a Write cycle, the Local Bus is floated by the 80188 only when the 80188 enters a "Hold Acknowledge" state.
2. INTA occurs one clock later in RMX-mode.
3. Status inactive just prior to T_4

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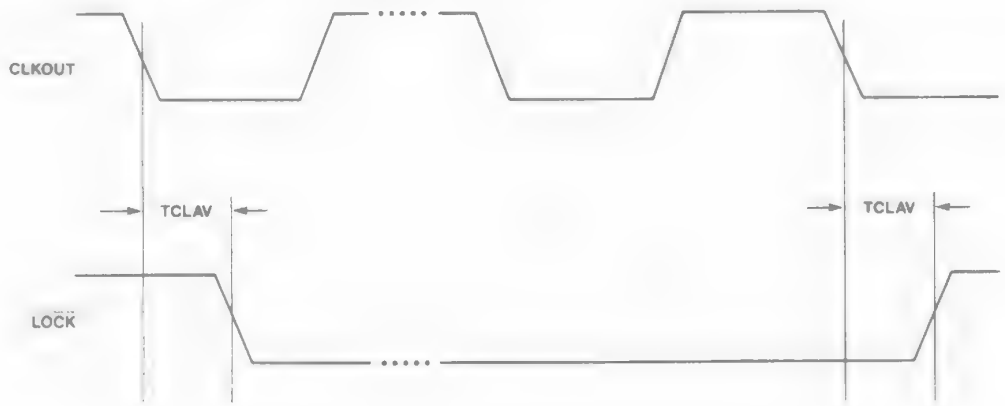
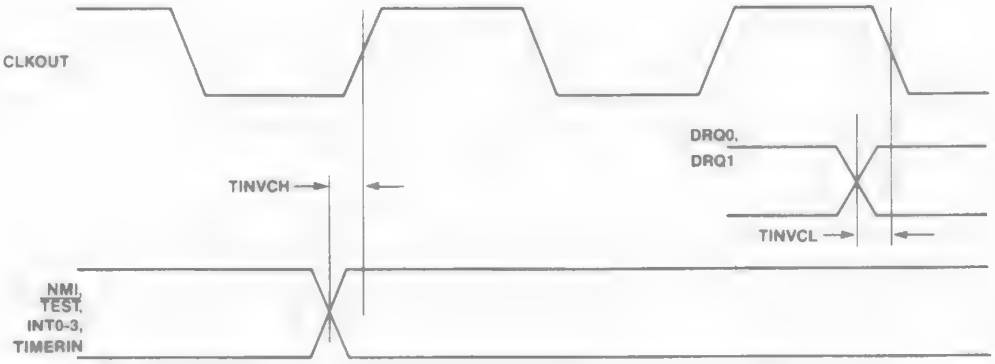
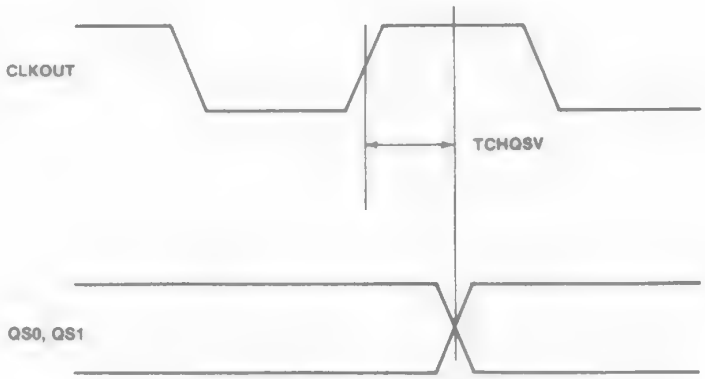
WAVEFORMS (Continued)







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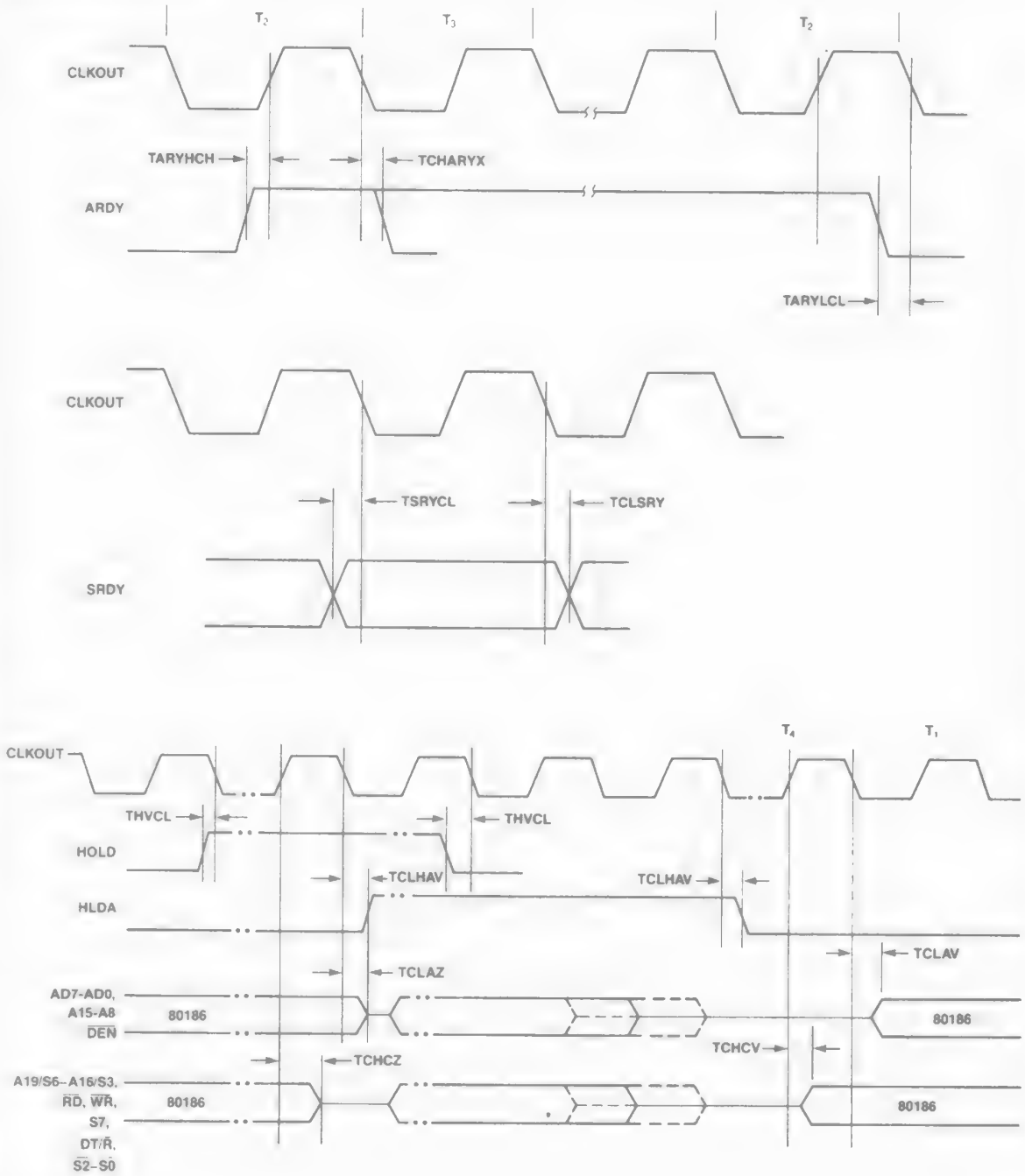
WAVEFORMS (Continued)

HOLD-HLDA TIMING



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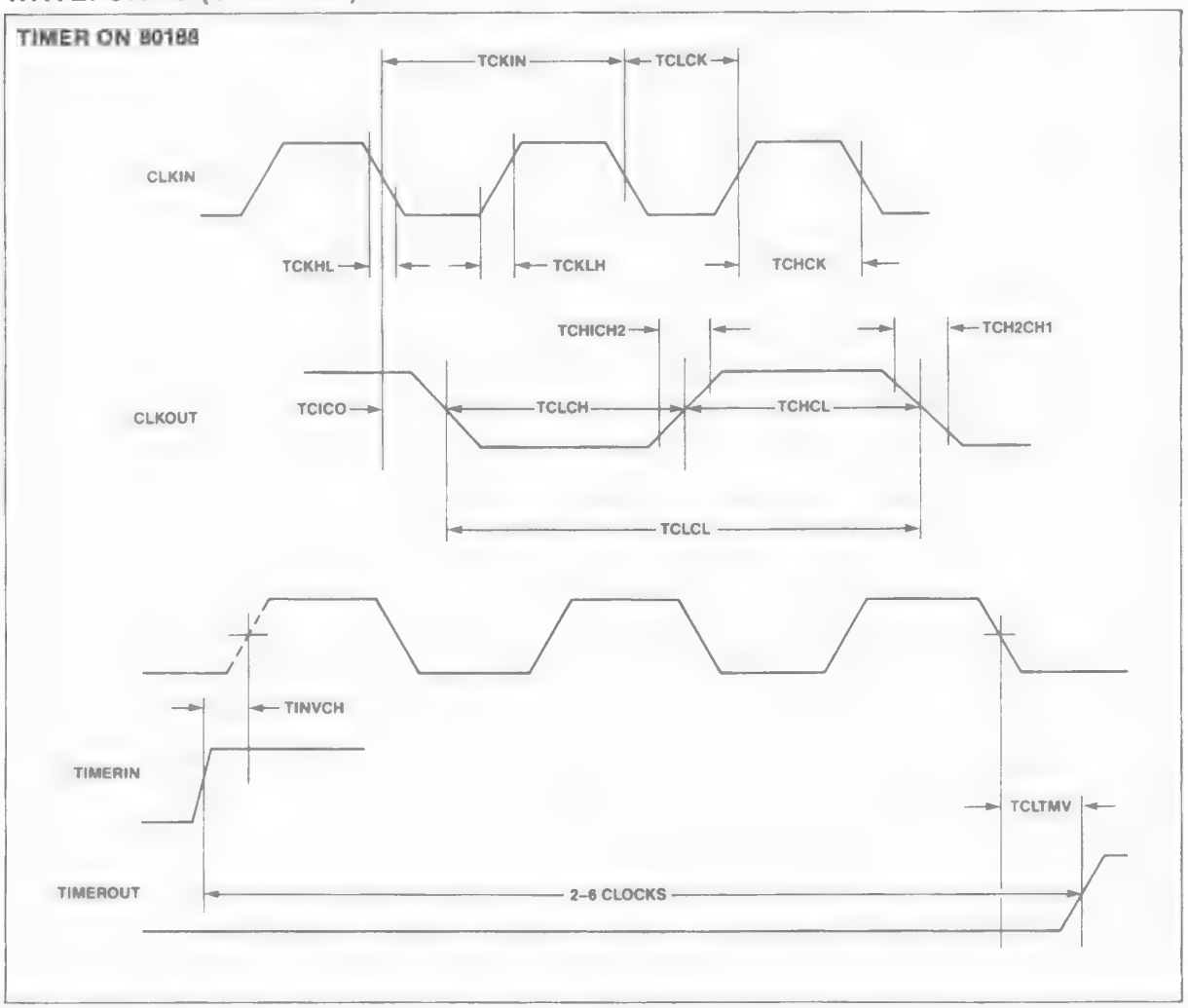
WAVEFORMS (Continued)



80188 INSTRUCTION TIMINGS

The following instruction timings represent the minimum execution time in clock cycles for each instruction. The timings given are based on the following assumptions:

- The opcode, along with any data or displacement required for execution of a particular instruction, has been prefetched and resides in the queue at the time it is needed.
- No wait states or bus HOLDS occur.
- All word-data is located on even-address boundaries.

All jumps and calls include the time required to fetch the opcode of the next instruction at the destination address.

All instructions which involve memory reference can require one (and in some cases, two) additional clocks above the minimum timings shown. This is due to the asynchronous nature of the handshake between the BIU and the Execution unit.

INSTRUCTION SET SUMMARY

FUNCTION	FORMAT				Clock Cycles	Comments
DATA TRANSFER						
MOV = Move:						
Register to Register/Memory	1 0 0 0 1 0 0 w	mod reg r/m			2/12*	
Register/memory to register	1 0 0 0 1 0 1 w	mod reg r/m			2/9*	
Immediate to register/memory	1 1 0 0 0 1 1 w	mod 0 0 0 r/m	data	data if w = 1	12–13*	8/16-bit
Immediate to register	1 0 1 1 w reg	data	data if w = 1		3–4	8/16-bit
Memory to accumulator	1 0 1 0 0 0 0 w	addr-low	addr-high		9*	
Accumulator to memory	1 0 1 0 0 0 1 w	addr-low	addr-high		8*	
Register/memory to segment register	1 0 0 0 1 1 1 0	mod 0 reg r/m			2/13	
Segment register to register/memory	1 0 0 0 1 1 0 0	mod 0 reg r/m			2/15	
PUSH = Push:						
Memory	1 1 1 1 1 1 1 1	mod 1 1 0 r/m			20	
Register	0 1 0 1 0 reg				14	
Segment register	0 0 0 reg 1 1 0				13	
Immediate	0 1 1 0 1 0 s 0	data	data if s = 0		14	
PUSHA = Push All	0 1 1 0 0 0 0 0				68	
POP = Pop:						
Memory	1 0 0 0 1 1 1 1	mod 0 0 0 r/m			24	
Register	0 1 0 1 1 reg				14	
Segment register	0 0 0 reg 1 1 1	(reg ≠ 01)			12	
POPA = Pop All	0 1 1 0 0 0 1 1				83	
XCHG = Exchange:						
Register/memory with register	1 0 0 0 0 1 1 w	mod reg r/m			4/17*	
Register with accumulator	1 0 0 1 0 reg				3	
IN = Input from:						
Fixed port	1 1 1 0 0 1 0 w	port			10*	
Variable port	1 1 1 0 1 1 0 w				8*	
OUT = Output to:						
Fixed port	1 1 1 0 0 1 1 w	port			9*	
Variable port	1 1 1 0 1 1 1 w				7*	
XLAT = Translate byte to AL	1 1 0 1 0 1 1 1				15	
LEA = Load EA to register	1 0 0 0 1 1 0 1	mod reg r/m			6	
LDS = Load pointer to DS	1 1 0 0 0 1 0 1	mod reg r/m	(mod ≠ 11)		26	
LES = Load pointer to ES	1 1 0 0 0 1 0 0	mod reg r/m	(mod ≠ 11)		26	
LAHF = Load AH with flags	1 0 0 1 1 1 1 1				2	
SAHF = Store AH into flags	1 0 0 1 1 1 1 0				3	
PUSHF = Push flags	1 0 0 1 1 1 0 0				13	
POPF = Pop flags	1 0 0 1 1 1 0 1				12	
SEGMENT = Segment Override						
CS	0 0 1 0 1 1 1 0				2	
SS	0 0 1 1 0 1 1 0				2	
DS	0 0 1 1 1 1 1 0				2	
ES	0 0 1 0 0 1 1 0				2	

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

*Note: Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT				Clock Cycles	Comments
ARITHMETIC						
ADD = Add:						
Reg/memory with register to either	0 0 0 0 0 0 d w	mod reg r/m			3/10*	
Immediate to register/memory	1 0 0 0 0 0 s w	mod 0 0 0 r/m	data	data if s w = 01	4/16*	
Immediate to accumulator	0 0 0 0 0 1 0 w	data	data if w = 1		3/4	8/16-bit
ADC = Add with carry:						
Reg/memory with register to either	0 0 0 1 0 0 d w	mod reg r/m			3/10*	
Immediate to register/memory	1 0 0 0 0 0 s w	mod 0 1 0 r/m	data	data if s w = 01	4/16*	
Immediate to accumulator	0 0 0 1 0 1 0 w	data	data if w = 1		3/4	8/16-bit
INC = Increment:						
Register/memory	1 1 1 1 1 1 1 w	mod 0 0 0 r/m			3/15*	
Register	0 1 0 0 0 reg				3	
SUB = Subtract:						
Reg/memory and register to either	0 0 1 0 1 0 d w	mod reg r/m			3/10*	
Immediate from register/memory	1 0 0 0 0 0 s w	mod 1 0 1 r/m	data	data if s w = 0 1	4/16*	
Immediate from accumulator	0 0 1 0 1 1 0 w	data	data if w = 1		3/4	8/16-bit
SBB = Subtract with borrow:						
Reg/memory and register to either	0 0 0 1 1 0 d w	mod reg r/m			3/10*	
Immediate from register/memory	1 0 0 0 0 0 s w	mod 0 1 1 r/m	data	data if s w = 0 1	4/16*	
Immediate from accumulator	0 0 0 1 1 1 0 w	data	data if w = 1		3/4	8/16-bit
DEC = Decrement:						
Register/memory	1 1 1 1 1 1 1 w	mod 0 0 1 r/m			3/15*	
Register	0 1 0 0 1 reg				3	
CMP = Compare:						
Register/memory with register	0 0 1 1 1 0 1 w	mod reg r/m			3/10*	
Register with register/memory	0 0 1 1 1 0 0 w	mod reg r/m			3/10*	
Immediate with register/memory	1 0 0 0 0 0 s w	mod 1 1 1 r/m	data	data if s w = 0 1	3/10*	
Immediate with accumulator	0 0 1 1 1 1 0 w	data	data if w = 1		3/4	8/16-bit
NEG = Change sign	1 1 1 1 0 1 1 w	mod 0 1 1 r/m			3	
AAA – ASCII adjust for add	0 0 1 1 0 1 1 1				8	
DAA – Decimal adjust for add	0 0 1 0 0 1 1 1				4	
AAS – ASCII adjust for subtract	0 0 1 1 1 1 1 1				7	
DAS – Decimal adjust for subtract	0 0 1 0 1 1 1 1				4	
MUL – Multiply (unsigned)	1 1 1 1 0 1 1 w	mod 1 0 0 r/m				
Register-Byte					26–28	
Register-Word					35–37	
Memory-Byte					32–34	
Memory-Word					41–43*	
IMUL – Integer multiply (signed)	1 1 1 1 0 1 1 w	mod 1 0 1 r/m				
Register-Byte					25–28	
Register-Word					34–37	
Memory-Byte					31–34	
Memory-Word					40–43*	
IMUL – Integer immediate multiply (signed)	0 1 1 0 1 0 s 1	mod reg r/m	data	data if s = 0	22–25/29–32*	
DIV – Divide (unsigned)	1 1 1 1 0 1 1 w	mod 1 1 0 r/m				
Register-Byte					29	
Register-Word					38	
Memory-Byte					35	
Memory-Word					44*	

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

*Note: Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT	Clock Cycles	Comments
ARITHMETIC (Continued):			
IDIV = Integer divide (signed)	1 1 1 1 0 1 1 w | mod 1 1 1 r/m		
Register-Byte		44–52	
Register-Word		53–61	
Memory-Byte		50–58	
Memory-Word		59–67*	
AAM – ASCII adjust for multiply	1 1 0 1 0 1 0 0 | 0 0 0 0 1 0 1 0	19	
AAD = ASCII adjust for divide	1 1 0 1 0 1 0 1 | 0 0 0 0 1 0 1 0	15	
CBW = Convert byte to word	1 0 0 1 1 0 0 0	2	
CWD – Convert word to double word	1 0 0 1 1 0 0 1	4	
LOGIC			
Shift/Rotate Instructions:			
Register/Memory by 1	1 1 0 1 0 0 0 w | mod TTT r/m	2/15*	
Register/Memory by CL	1 1 0 1 0 0 1 w | mod TTT r/m	5+n/17+n*	
Register/Memory by Count	1 1 0 0 0 0 0 w | mod TTT r/m | count	5+n/17+n*	
	TTT Instruction 0 0 0 ROL 0 0 1 ROR 0 1 0 RCL 0 1 1 RCR 1 0 0 SHL/SAL 1 0 1 SHR 1 1 1 SAR		
AND = And:			
Reg/memory and register to either	0 0 1 0 0 0 d w | mod reg r/m	3/10*	
Immediate to register/memory	1 0 0 0 0 0 0 w | mod 1 0 0 r/m | data | data if w = 1	4/16*	
Immediate to accumulator	0 0 1 0 0 1 0 w | data | data if w = 1	3/4	8/16-bit
TEST = And function to flags, no result:			
Register/memory and register	1 0 0 0 0 1 0 w | mod reg r/m	3/10*	
Immediate data and register/memory	1 1 1 1 0 1 1 w | mod 0 0 0 r/m | data | data if w = 1	4/10*	
Immediate data and accumulator	1 0 1 0 1 0 0 w | data | data if w = 1	3/4	8/16-bit
OR = Or:			
Reg/memory and register to either	0 0 0 0 1 0 d w | mod reg r/m	3/10*	
Immediate to register/memory	1 0 0 0 0 0 0 w | mod 0 0 1 r/m | data | data if w = 1	4/16*	
Immediate to accumulator	0 0 0 0 1 1 0 w | data | data if w = 1	3/4	8/16-bit
XOR = Exclusive or:			
Reg/memory and register to either	0 0 1 1 0 0 d w | mod reg r/m	3/10*	
Immediate to register/memory	1 0 0 0 0 0 0 w | mod 1 1 0 r/m | data | data if w = 1	4/16*	
Immediate to accumulator	0 0 1 1 0 1 0 w | data | data if w = 1	3/4	8/16-bit
NOT – Invert register/memory	1 1 1 1 0 1 1 w | mod 0 1 0 r/m	3	
STRING MANIPULATION:			
MOVS = Move byte/word	1 0 1 0 0 1 0 w	14*	
CMPS = Compare byte/word	1 0 1 0 0 1 1 w	22*	
SCAS = Scan byte/word	1 0 1 0 1 1 1 w	15*	
LODS – Load byte/wd to AL/AX	1 0 1 0 1 1 0 w	12*	
STOS – Stor byte/wd from AL/A	1 0 1 0 1 0 1 w	10*	
INS = Input byte/wd from DX port	0 1 1 0 1 1 0 w	14*	
OUTS = Output byte/wd to DX port	0 1 1 0 1 1 1 w	14*	

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

*Note: Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT	Clock Cycles	Comments
STRING MANIPULATION (Continued)			
Repeated by count in CX			
MOVS		8+8n*	
CMPS		5+22n*	
SCAS Scan string		5+15n*	
LODS		6+11n*	
STOS		6+9n*	
INS		8+8n*	
OUTS	0 0 1 0 0 1 1 1 w	8+8n*	
CONTROL TRANSFER			
CALL = Call			
Direct within segment		18	
Register memory indirect within segment	1 1 1 1 1 1 1 1 mod 0 1 0 r/m	17/27	
Direct intersegment	segment offset segment selector	31	
Indirect intersegment		54	
JMP = Unconditional jump			
Short long		13	
Direct within segment		13	
Register memory indirect within segment	1 1 1 1 1 1 1 1 mod 1 0 0 r/m	11/21	
Direct intersegment	segment offset segment selector	13	
Indirect intersegment		34	
RET = Return from CALL			
Within segment		20	
Within seg adding immed to SP		22	
Intersegment		30	
Intersegment adding immediate to SP		33	

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

*Note: Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT	Clock Cycles	Comments
CONTROL TRANSFER (Continued):			
JE/JZ – Jump on equal/zero	0 1 1 1 0 1 0 0 disp	4/13	13 if JMP taken 4 if JMP not taken
JL/JNGE – Jump on less/not greater or equal	0 1 1 1 1 1 0 0 disp	4/13	
JLE/JNG – Jump on less or equal/not greater	0 1 1 1 1 1 1 0 disp	4/13	
JB/JNAE – Jump on below/not above or equal	0 1 1 1 0 0 1 0 disp	4/13	
JBE/JNA – Jump on below or equal/not above	0 1 1 1 0 1 1 0 disp	4/13	
JP/JPE – Jump on parity/parity even	0 1 1 1 1 0 1 0 disp	4/13	
JO – Jump on overflow	0 1 1 1 0 0 0 0 disp	4/13	
JS – Jump on sign	0 1 1 1 1 0 0 0 disp	4/13	
JNE/JNZ – Jump on not equal/not zero	0 1 1 1 0 1 0 1 disp	4/13	
JNL/JGE – Jump on not less/greater or equal	0 1 1 1 1 1 0 1 disp	4/13	
JNLE/JG – Jump on not less or equal/greater	0 1 1 1 1 1 1 1 disp	4/13	
JNB/JAE – Jump on not below/above or equal	0 1 1 1 0 0 1 1 disp	4/13	
JNBE/JA – Jump on not below or equal/above	0 1 1 1 0 1 1 1 disp	4/13	
JNP/JPO – Jump on not parity/parity odd	0 1 1 1 1 0 1 1 disp	4/13	
JNO – Jump on not overflow	0 1 1 1 0 0 0 1 disp	4/13	
JNS – Jump on not sign	0 1 1 1 1 0 0 1 disp	4/13	
LOOP – Loop CX times	1 1 1 0 0 0 1 0 disp	5/15	
LOOPZ/LOOPE – Loop while zero/equal	1 1 1 0 0 0 0 1 disp	6/16	
LOOPNZ/LOOPNE – Loop while not zero/equal	1 1 1 0 0 0 0 0 disp	6/16	
JCXZ – Jump on CX zero	1 1 1 0 0 0 1 1 disp	16 5	JMP taken/ JMP not taken
ENTER – Enter Procedure	1 1 0 0 1 0 0 0 data-low data-high L	15 25 22 + 16(n - 1)	
LEAVE – Leave Procedure	1 1 0 0 1 0 0 1	8	
INT = Interrupt:			
Type specified	1 1 0 0 1 1 0 1 type	67	
Type 3	1 1 0 0 1 1 0 0	65	if INT. taken/ if INT. not taken
INTO – Interrupt on overflow	1 1 0 0 1 1 1 0	68/4	
IRET – Interrupt return	1 1 0 0 1 1 1 1	40	
BOUND – Detect value out of range	0 1 1 0 0 0 1 0 mod reg r/m	41-43	

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT	Clock Cycles	Comments
PROCESSOR CONTROL			
CLC - Clear carry	1 1 1 1 1 0 0 0	2	
CMC – Complement carry	1 1 1 1 0 1 0 1	2	
STC = Set carry	1 1 1 1 1 0 0 1	2	
CLD Clear direction	1 1 1 1 1 1 0 0	2	
STD = Set direction	1 1 1 1 1 1 0 1	2	
CLI – Clear interrupt	1 1 1 1 1 0 1 0	2	
STI = Set interrupt	1 1 1 1 1 0 1 1	2	
HLT - Halt	1 1 1 1 0 1 0 0	2	
WAIT - Wait	1 0 0 1 1 0 1 1	5	if $\overline{test}$ = 0
LOCK = Bus lock prefix	1 1 1 1 0 0 0 0	2	
ESC = Processor Extension Escape	1 0 0 1 1 T T T | mod LLL r m (TTT LLL are opcode to processor extension)	6	

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

FOOTNOTES

The effective Address (EA) of the memory operand is computed according to the mod and r/m fields:

if mod = 11 then r/m is treated as a REG field
if mod = 00 then DISP = 0*, disp-low and disp-high are absent
if mod = 01 then DISP = disp-low sign-extended to 16-bits, disp-high is absent
if mod = 10 then DISP = disp-high: disp-low

if r/m = 000 then EA = (BX) + (SI) + DISP
if r/m = 001 then EA = (BX) + (DI) + DISP
if r/m = 010 then EA = (BP) + (SI) + DISP
if r/m = 011 then EA = (BP) + (DI) + DISP
if r/m = 100 then EA = (SI) + DISP
if r/m = 101 then EA = (DI) + DISP
if r/m = 110 then EA = (BP) + DISP*
if r/m = 111 then EA = (BX) + DISP

DISP follows 2nd byte of instruction (before data if required)

*except if mod = 00 and r/m = 110 then EA = disp-high: disp-low.

EA calculation time is 4 clock cycles for all modes, and is included in the execution times given whenever appropriate.

SEGMENT OVERRIDE PREFIX

0	0	1	reg	1	1	0

reg is assigned according to the following:

reg	Segment Register
00	ES
01	CS
10	SS
11	DS

REG is assigned according to the following table:

16-Bit (w = 1)	8-Bit (w = 0)
000 AX	000 AL
001 CX	001 CL
010 DX	010 DL
011 BX	011 BL
100 SP	100 AH
101 BP	101 CH
110 SI	110 DH
111 DI	111 BH

The physical addresses of all operands addressed by the BP register are computed using the SS segment register. The physical addresses of the destination operands of the string primitive operations (those addressed by the DI register) are computed using the ES segment, which may not be overridden.

PRELIMINARY

8089
8 & 16-BIT HMOS I/O PROCESSOR

- **High Speed DMA Capabilities Including I/O to Memory, Memory to I/O, Memory to Memory, and I/O to I/O**
- **iAPX 86, 88 Compatible: Removes I/O Overhead from CPU in iAPX 86/11 or 88/11 Configuration**
- **Allows Mixed Interface of 8- & 16-Bit Peripherals, to 8- & 16-Bit Processor Busses**
- **1 Mbyte Addressability**
- **Memory Based Communication with CPU**
- **Supports LOCAL or REMOTE I/O Processing**
- **Flexible, Intelligent DMA Functions Including Translation, Search, Word Assembly/Disassembly**
- **MULTIBUS™ Compatible System Interface**
- **Available in EXPRESS – Standard Temperature Range**

The Intel® 8089 is a revolutionary concept in microprocessor input/output processing. Packaged in a 40-pin DIP package, the 8089 is a high performance processor implemented in N-channel, depletion load silicon gate technology (HMOS). The 8089's instruction set and capabilities are optimized for high speed, flexible and efficient I/O handling. It allows easy interface of Intel's 16-bit iAPX 86 and 8-bit iAPX 88 microprocessors with 8- and 16-bit peripherals. In the REMOTE configuration, the 8089 bus is user definable allowing it to be compatible with any 8/16-bit Intel microprocessor, interfacing easily to the Intel multiprocessor system bus standard MULTIBUS™.

The 8089 performs the function of an intelligent DMA controller for the Intel iAPX 86, 88 family and with its processing power, can remove I/O overhead from the iAPX 86 or iAPX 88. It may operate completely in parallel with a CPU, giving dramatically improved performance in I/O intensive applications. The 8089 provides two I/O channels, each supporting a transfer rate up to 1.25 mbyte/sec at the standard clock frequency of 5 MHz. Memory based communication between the IOP and CPU enhances system flexibility and encourages software modularity, yielding more reliable, easier to develop systems.

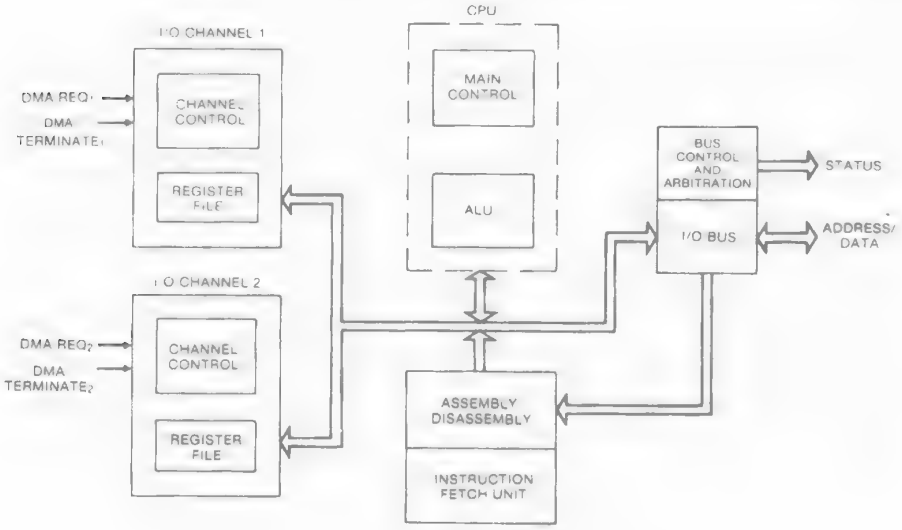


Figure 1. 8089 I/O Processor Block Diagram

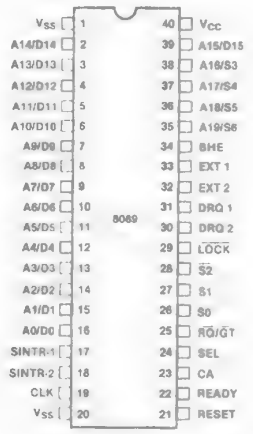


Figure 2. 8089 Pin Configuration

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Table 1. Pin Description

Symbol	Type	Name and Function
A0–A15/ D0–D15	I/O	**Multiplexed Address and Data Bus:** The function of these lines are defined by the state of $\overline{S0}$, $\overline{S1}$ and $\overline{S2}$ lines. The pins are floated after reset and when the bus is not acquired. A8–A15 are stable on transfers to a physical 8-bit data bus (same bus as 8088), and are multiplexed with data on transfers to a 16-bit physical bus.
A16–A19/ S3–S6	O	**Address and Status:** Multiplexed most significant address lines and status information. The address lines are active only when addressing memory. Otherwise, the status lines are active and are encoded as shown below. The pins are floated after reset and when the bus is not acquired. **S6 S5 S4 S3** 1 1 0 0 DMA cycle on CH1 1 1 0 1 DMA cycle on CH2 1 1 1 0 Non-DMA cycle on CH1 1 1 1 1 Non-DMA cycle on CH2
$\overline{BHE}$	O	**Bus High Enable:** The Bus High Enable is used to enable data operations on the most significant half of the data bus (D8–D15). The signal is active low when a byte is to be transferred on the upper half of the data bus. The pin is floated after reset and when the bus is not acquired. $\overline{BHE}$ does not have to be latched.
$\overline{S0}$, $\overline{S1}$, $\overline{S2}$	O	**Status:** These are the status pins that define the IOP activity during any given cycle. They are encoded as shown below: **$\overline{S2}$ $\overline{S1}$ $\overline{S0}$** 0 0 0 Instruction fetch; I/O space 0 0 1 Data fetch; I/O space 0 1 0 Data store; I/O space 0 1 1 Not used 1 0 0 Instruction fetch; System Memory 1 0 1 Data fetch; System Memory 1 1 0 Data store; System Memroy 1 1 1 Passive The status lines are utilized by the bus controller and bus arbiter to generate all memory and I/O control signals. The signals change during T4 if a new cycle is to be entered while the return to passive state in T3 or T_W indicates the end of a cycle. The pins are floated after system reset and when the bus is not acquired.
READY	I	**Ready:** The ready signal received from the addressed device indicates that the device is ready for data transfer. The signal is active high and is synchronized by the 8284 clock generator.
$\overline{LOCK}$	O	**Lock:** The lock output signal indicates to the bus controller that the bus is needed for more than one contiguous cycle. It is set via the channel control register, and during the TSL instruction. The pin floats after reset and when the bus is not acquired. This output is active low.
RESET	I	**Reset:** The receipt of a reset signal causes the IOP to suspend all its activities and enter an idle state until a channel attention is received. The signal must be active for at least four clock cycles
CLK	I	**Clock:** Clock provides all timing needed for internal IOP operation.
CA	I	**Channel Attention:** Gets the attention of the IOP. Upon the falling edge of this signal, the SEL input pin is examined to determine Master/Slave or CH1/CH2 information. This input is active high.
SEL	I	**Select:** The first CA received after system reset informs the IOP via the SEL line, whether it is a Master or Slave (0/1 for Master/Slave respectively) and starts the initialization sequence. During any other CA the SEL line signifies the selection of CH1/CH2. (0/1 respectively.)
DRQ1–2	I	**Data Request:** DMA request inputs which signal the IOP that a peripheral is ready to transfer/receive data using channels 1 or 2 respectively. The signals must be held active high until the appropriate fetch/stroke is initiated.
$\overline{RQ}/\overline{GT}$	I/O	**Request Grant:** Request Grant implements the communication dialogue required to arbitrate the use of the system bus (between IOP and CPU, LOCAL mode) or I/O bus when two IOPs share the same bus (REMOTE mode). The $\overline{RQ}/\overline{GT}$ signal is active low. An internal pull-up permits $\overline{RQ}/\overline{GT}$ to be left floating if not used.
SINTR1–2	O	**Signal Interrupt:** Signal Interrupt outputs from channels 1 and 2 respectively. The interrupts may be sent directly to the CPU or through the 8295A interrupt controller. They are used to indicate to the system the occurrence of user defined events.
EXT1–2	I	**External Terminate:** External terminate inputs for channels 1 and 2 respectively. The EXT signals will cause the termination of the current DMA transfer operation if the channel is so programmed by the channel control register. The signal must be held active high until termination is complete.
V_{CC}		**Voltage:** +5 volt power input.
V_{SS}		**Ground.**

FUNCTIONAL DESCRIPTION

The 8089 IOP has been designed to remove I/O processing, control and high speed transfers from the central processing unit. Its major capabilities include that of initializing and maintaining peripheral components and supporting versatile DMA. This DMA function boasts flexible termination conditions (such as external terminate, mask compare, single transfer and byte count expired). The DMA function of the 8089 IOP uses a two cycle approach where the information actually flows through the 8089 IOP. This approach to DMA vastly simplifies the bus timings and enhances compatibility with memory and peripherals, in addition to allowing operations to be performed on the data as it is transferred. Operations can include such constructs as translate, where the 8089 automatically vectors through a lookup table and mask compare, both on the "fly".

The 8089 is functionally compatible with Intel's iAPX 86, 88 family. It supports any combination of 8/16-bit busses. In the REMOTE mode it can be used to complement other Intel processor families. Hardware and communication architecture are designed to provide simple mechanisms for system upgrade.

The only direct communication between the IOP and CPU is handled by the Channel Attention and Interrupt lines. Status information, parameters and task programs are passed via blocks of shared memory, simplifying hardware interface and encouraging structured programming.

The 8089 can be used in applications such as file and buffer management in hard disk or floppy disk control. It can also provide for soft error recovery routines and scan control. CRT control, such as cursor control and auto scrolling, is simplified with the 8089. Keyboard control, communication control and general I/O are just a few of the typical applications for the 8089.

Remote and Local Modes

Shown in Figure 3 is the 8089 in a LOCAL configuration. The iAPX 86 (or iAPX 88) is used in its maximum mode. The 8089 and iAPX 86 reside on the same local bus, sharing the same set of system buffers. Peripherals located on the system bus can be addressed by either the iAPX 86 or the 8089. The 8089 requests the use of the LOCAL bus by means of the RQ/GT line. This performs a similar function to that of HOLD and HLDA on the Intel 8085A, 8080A and iAPX 86 minimum mode, but is implemented on one physical line. When the iAPX 86 relinquishes the system bus, the 8089 uses the same bus control, latches and transceiver components to generate the system address, control and data lines. This mode allows a more economical system configuration at the expense of reduced CPU thruput due to IOP bus utilization.

A typical REMOTE configuration is shown in Figure 4. In this mode, the IOP's bus is physically separated from the system bus by means of system buffers/latches. The IOP maintains its own local bus and can operate out of local or system memory. The system bus interface contains the following components:

- Up to three 8282 buffer/latches to latch the address to the system bus.
- Up to two 8286 devices bidirectionally buffer the system data bus.

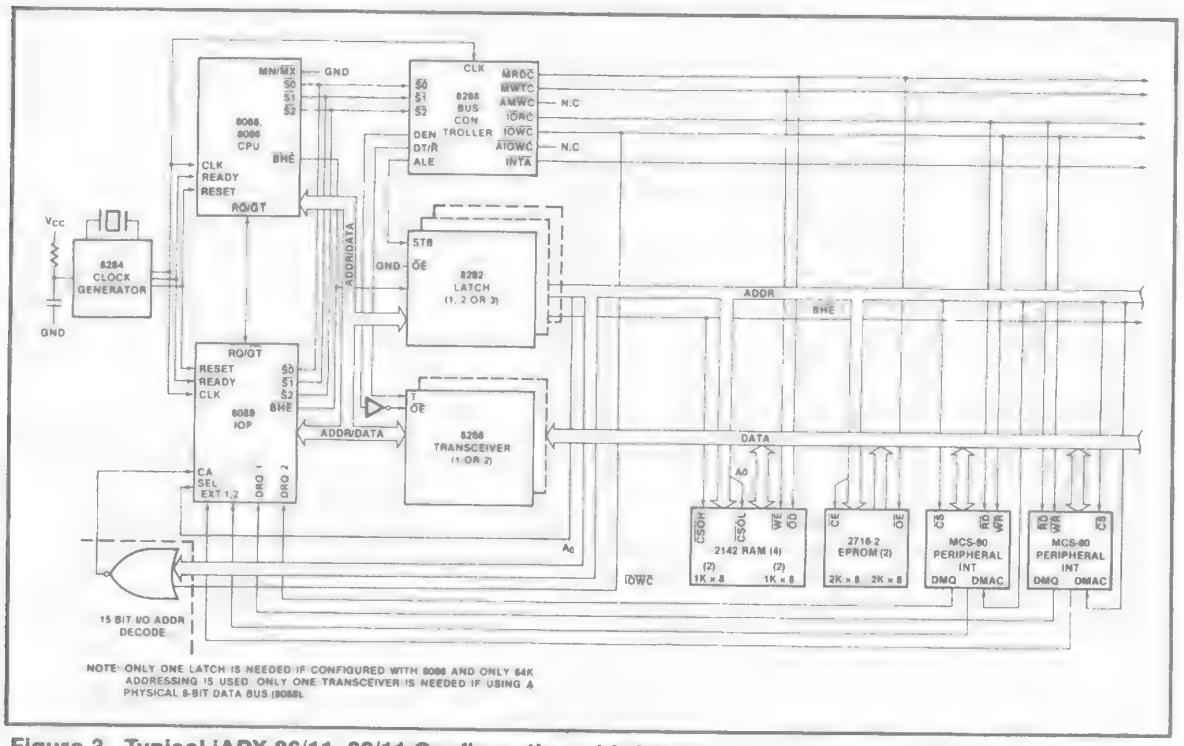


Figure 3. Typical iAPX 86/11, 88/11 Configuration with 8089 in LOCAL Mode, 8088, 8086 in MAX Mode

- An 8288 bus controller supplies the control signals necessary for buffer operation as well as MRDC (Memory Read) and MWTC (Memory Write) signals.
- An 8289 bus arbiter performs all the functions necessary to arbitrate the use of the system bus. This is used in place of the $\overline{RQ}/\overline{GT}$ logic in the LOCAL mode. This arbiter decodes type of cycle information from the 8089 status lines to determine if the IOP desires to perform a transfer over the "common" or system bus.

The peripheral devices PER1 and PER2 are supported on their own data and address bus. the 8089 communicates with the peripherals without affecting system bus operation. Optional buffers may be used on the local bus when capacitive loading conditions so dictate. I/O programs and RAM buffers may also reside on the local bus to further reduce system bus utilization.

COMMUNICATION MECHANISM

Fundamentally, communication between the CPU and IOP is performed through messages prepared in shared memory. The CPU can cause the 8089 to execute a program by placing it in the 8089's memory space and/or directing the 8089's attention to it by asserting a hardware Channel Attention (CA) signal to the IOP, activating the proper I/O channel. The SEL Pin indicates to the IOP which channel is being addressed. Communication from the IOP to the processor can be performed in a similar manner via a system interrupt (SINTR 1,2), if the CPU has enabled interrupts for this purpose. Additionally, the 8089 can store messages in memory regarding its status and the status of any peripherals. This communication mechanism is supported by a hierarchial data structure to provide a maximum amount of flexibility of memory use with the added capability of handling multiple IOP's.

Illustrated in Figure 5 is an overview of the communication data structure hierarchy that exists for the 8089 I/O processor. Upon the first CA from RESET, if the IOP is initialized as the BUS MASTER, 5 bytes of information are read into the 8089 starting at location FFFF6 (FFFF6, FFFF8-FFFFB) where the type of system bus (16-bit or 8-bit) and pointers to the system configuration block are obtained. This is the only fixed location the 8089 accesses. The remaining addresses are obtained via the data structure hierarchy. The 8089 determines addresses in the same manner as does the iAPX 86; i.e., a 16-bit relocation pointer is offset left 4 bits and added to the 16-bit address offset, obtaining a 20-bit address. Once these 20-bit addresses are formed, they are stored as such, as all the 8089 address registers are 20 bits long. After the system configuration pointer address is formed, the 8089 IOP accesses the system configuration block.

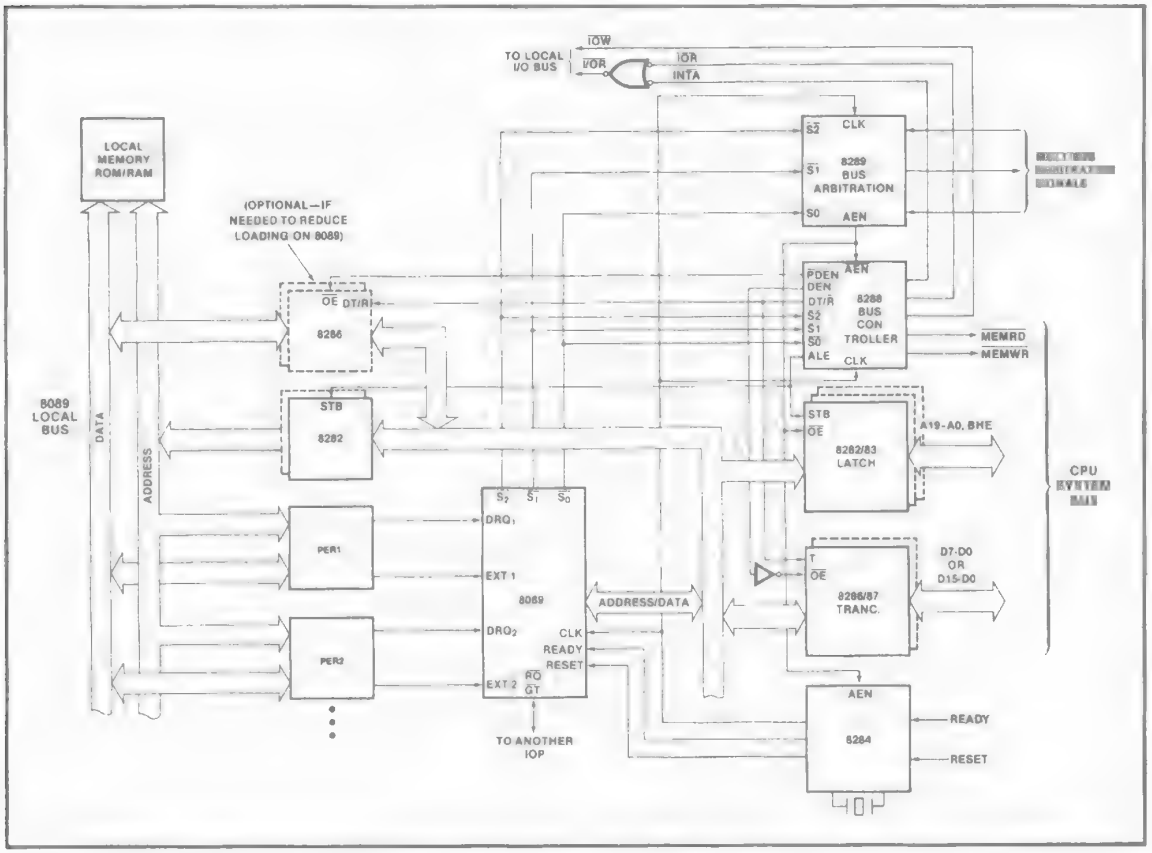


Figure 4. Typical REMOTE Configuration

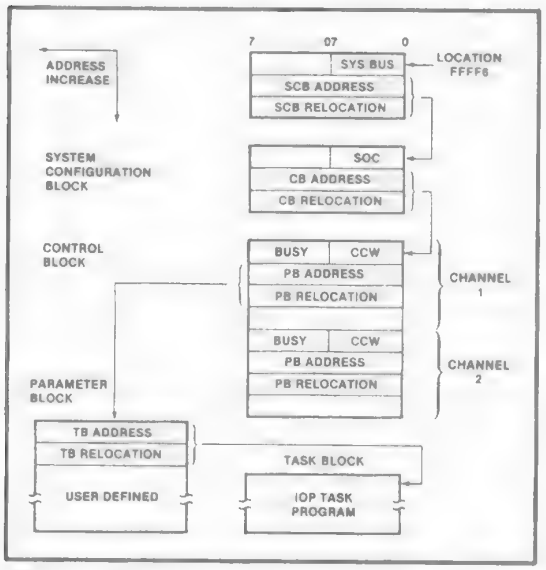


Figure 5. Communication Data Structure Hierarchy

The System Configuration Block (SCB), used only during startup, points to the Control Block (CB) and provides IOP system configuration data via the SOC byte. The SOC byte initializes IOP I/O bus width to 8/16, and defines one of two IOP $\overline{RQ}/\overline{GT}$ operating modes. For $\overline{RQ}/\overline{GT}$ mode 0, the IOP is typically initialized as SLAVE and has its $\overline{RQ}/\overline{GT}$ line tied to a MASTER CPU (typical LOCAL configuration). In this mode, the CPU normally has control of the bus, grants control to the IOP as needed, and has the bus restored to it upon IOP task completion (IOP request—CPU grant—IOP done). For $\overline{RQ}/\overline{GT}$ mode 1, useful only in remote mode between two IOPs, MASTER/SLAVE designation is used only to initialize bus control: from then on, each IOP requests and grants as the bus is needed (IOP1 request—IOP2 grant—IOP2 request—IOP1 grant). Thus, each IOP retains bus control until the other requests it. The completion of initialization is signalled by the IOP clearing the BUSY flag in the CB. This type of startup allows the user to have the startup pointers in ROM with the SCB in RAM. Allowing the SCB to be in RAM gives the user the flexibility of being able to initialize multiple IOPs.

The Control Block furnishes bus control initialization for the IOP operation (CCW or Channel Control Word) and provides pointers to the Parameter Block or "data" memory for both channels 1 and 2. The CCW is retrieved and analyzed upon all CA's other than the first after a reset. The CCW byte is decoded to determine channel operation.

The Parameter Block contains the address of the Task Block and acts as a messge center between the IOP and CPU. Parameters or variable information is passed from the CPU to its IOP in this block to customize the software interface to the peripheral device. It is also used for transferring data and status information between the IOP and CPU.

The Task Block contains the instructions for the respective channel. This block can reside on the local bus of the IOP, allowing the IOP to operate concurrently with the CPU, or reside in system memory.

The advantage of this type of communication between the processor, IOP and peripheral, is that it allows for a very clean method for the operating system to handle I/O routines. Canned programs or "Task Blocks" allow for execution of general purpose I/O routines with the status and peripheral command information being passed via the Parameter Block ("data" memory). Task Blocks (or "program" memory) can be terminated or restarted by the CPU, if need be. Clearly, the flexibility of this communication lends itself to modularity and applicability to a large number of peripheral devices and upward compatibility to future end user systems and microprocessor families.

Register Set

The 8089 maintains separate registers for its two I/O channels as well as some common registers (see Figure 6). There are sufficient registers for each channel to sustain its own DMA transfers, and process its own instruction stream. The basic DMA pointer registers (GA, GB — 20 bits each), can point to either the system bus or local bus, DMA source or destination, and can be autoincremented. A third register set (GC) can be used to allow translation during the DMA process through a lookup table it points to. Additionally, registers are provided for a masked compare during the data transfer and can be set up to act as one of the termination conditions. Other registers are also provided. Many of these registers can be used as general purpose registers during program execution, when the IOP is not performing DMA cycles.

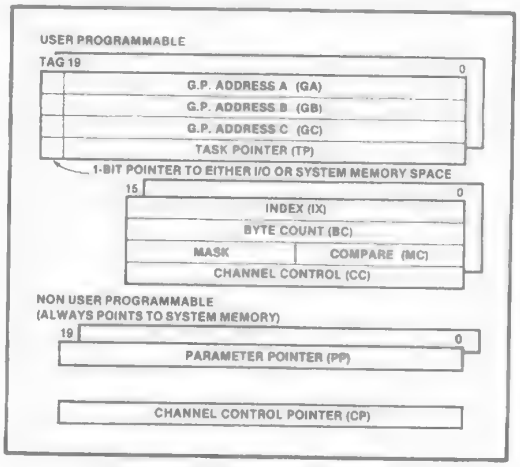


Figure 6. Register Model

Bus Operation

The 8089 utilizes the same bus structure as the iAPX 86, 88 in their maximum mode configurations (see Figure 7). The address is time multiplexed with the data on the first 16/8 lines. A16 through A19 are time multiplexed with four status lines S3-S6. For 8089 cycles, S4 and S3 determine what type of cycle (DMA versus non-DMA) is being performed on channels 1 or 2. S5 and S6

are a unique code assigned to the 8089 IOP, enabling the user to detect which processor is performing a bus cycle in a multiprocessing environment.

The first three status lines, S0-S2, are used with an 8288 bus controller to determine if an instruction fetch or data transfer is being performed in I/O or system memory space.

DMA transfers require at least two bus cycles with each bus cycle requiring a minimum of four clock cycles. Additional clock cycles are added if wait states are required. This two cycle approach simplifies considerably the bus timings in burst DMA. The 8089 optimizes the transfer between two different bus widths by using three bus cycles versus four to transfer 1 word. More than one read (write) is performed when mapping an 8-bit bus onto a 16-bit bus (vice versa). For example, a data transfer from an 8-bit peripheral to a 16-bit physical location in memory is performed by first doing two reads, with word assembly within the IOP assembly register file and then one write.

As can be expected, the data bandwidth of the IOP is a function of the physical bus width of the system and I/O busses. Table 2 gives the bandwidth, latency and bus utilization of the 8089. The system bus is assumed to be 16-bits wide with either an 8-bit peripheral (under byte column) or 16-bit peripheral (word column) being shown.

The latency refers to the worst case response time by the IOP to a DMA request, without the bus arbitration times. Notice that the word transfer allows 50% more bandwidth. This occurs since three bus cycles are required to map 8-bit data into a 16-bit location, versus two for a 16-bit to 16-bit transfer. Note that it is possible to fully saturate the system bus in the LOCAL mode whereas in the REMOTE mode this is reduced to a maximum of 50%.

Table 2. Achievable 5 MHz 8089 Operations with a 16-Bit System Bus

	Local		Remote	
	Byte	Word	Byte	Word
Bandwidth	830 KB/S	1250 KB/S	830 KB/S	1250 KB/S
Latency	1.0/2.4 μsec*	1.0/2.4 μsec*	1.0/2.4 μsec*	1.0/2.4 μsec*
System Bus Utilization	2.4 μsec PER TRANSFER	1.6 μsec PER TRANSFER	0.8 μsec PER TRANSFER	0.8 μsec PER TRANSFER

*2.4 μsec if interleaving with other channel and no wait states. 1μsec if channel is waiting for request.

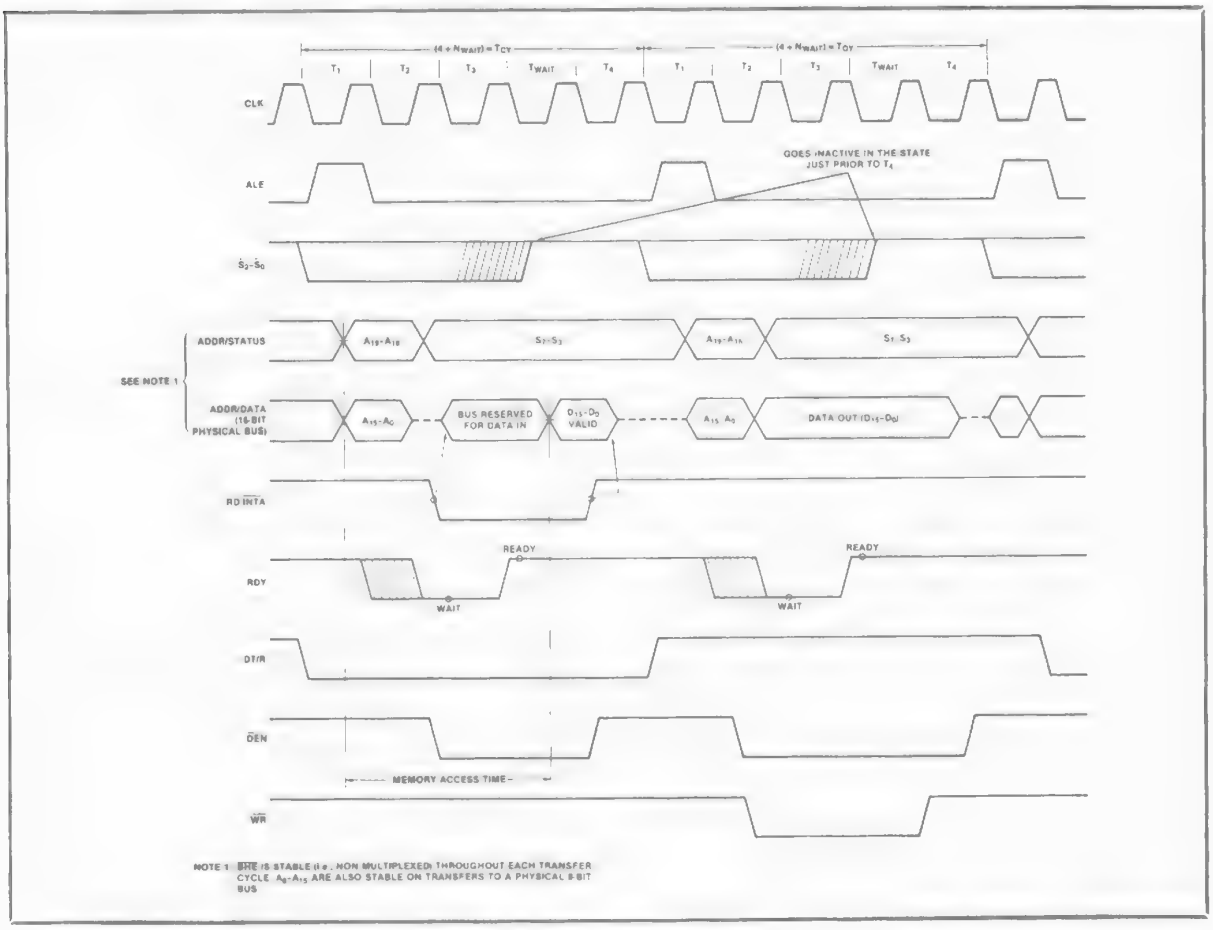


Figure 7. 8089 Bus Operation

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias.....0°C to 70°C
Storage Temperature.....−65°C to +150°C
Voltage on Any Pin with
Respect to Ground..... −1.0 to +7V
Power Dissipation ..... 2.5 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ±10%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	+0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + 1.0	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2.0 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400 μA
I_{CC}	Power Supply Current		350	mA	T_A = 25°C
I_{LI}	Input Leakage Current(1)		±10	μA	0V < VIN < V_{CC}
I_{LO}	Output Leakage Current		±10	μA	0.45V ≤ V_{OUT} ≤ V_{CC}
V_{CL}	Clock Input Low Voltage	−0.5	+0.6	V	
V_{CH}	Clock Input High Voltage	3.9	V_{CC} + 1.0	V	
C_{IN}	Capacitance of Input Buffer (All input except $AD_0 - AD_{15}$, $\overline{RQ}/\overline{GT}$)		15	pF	fc = 1 MHz
C_{IO}	Capacitance of I/O Buffer ($AD_0 - AD_{15}$, $\overline{RQ}/\overline{GT}$)		15	pF	fc = 1 MHz

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ±10%)

8089/8086 MAX MODE SYSTEM (USING 8288 BUS CONTROLLER) TIMING REQUIREMENTS

Symbol	Parameter	Min.	Max.	Units	Test Conditions
TCLCL	CLK Cycle Period	200	500	ns	
TCLCH	CLK Low Time	(⅔TCLCL) − 15		ns	
TCHCL	CLK High Time	(⅓TCLCL) + 2		ns	
TCH1CH2	CLK Rise Time		10	ns	From 1.0V to 3.5V
TCL2CL1	CLK Fall Time		10	ns	From 3.5V to 1.0V
TDVCL	Data In Setup Time	30		ns	
TCLDX	Data In Hold Time	10		ns	
TR1VCL	RDY Setup Time into 8284 (See Notes 1, 2)	35		ns	
TCLR1X	RDY Hold Time into 8284 (See Notes 1, 2)	0		ns	
TRYHCH	READY Setup Time into 8089	(⅔TCLCL) − 15		ns	
TCHRYX	READY Hold Time into 8089	30		ns	
TRYLCL	READY Inactive to CLK (See Note 4)	−8		ns	
TINVCH	Setup Time Recognition (DRQ 1,2 RESET, Ext 1,2) (See Note 2)	30		ns	
TGVCH	$\overline{RQ}/\overline{GT}$ Setup Time	30		ns	
TCAHCAL	CA Width	95		ns	
TSLVCAL	SEL Setup Time	75		ns	
TCALSLX	SEL Hold Time	0		ns	
TCHGX	GT Hold Time into 8089	40		ns	
TILIH	Input Rise Time (Except CLK)		20	ns	From 0.8V to 2.0V
TIHIL	Input Fall Time (Except CLK)		12	ns	From 2.0V to 0.8V

AFN-00840E

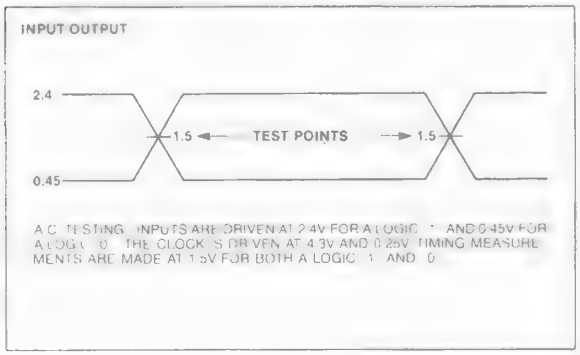
A.C. CHARACTERISTICS (Continued)

TIMING RESPONSES

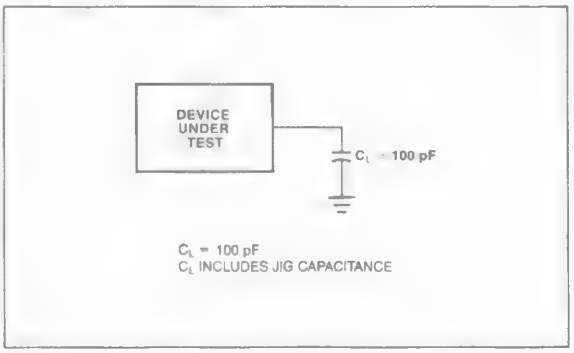
Symbol	Parameter	Min.	Max.	Units	Test Conditions
TCLML	Command Active Delay (See Note 1)	10	35	ns	$C_L = 80$ pF
TCLMH	Command Inactive Delay (See Note 1)	10	35	ns	
TRYHSH	READY Active to Status Passive (See Note 3)		110	ns	
TCHSV	Status Active Delay	10	110	ns	
TCLSH	Status Inactive Delay	10	130	ns	
TCLAV	Address Valid Delay	10	110	ns	
TCLAX	Address Hold Time	10		ns	
TCLAZ	Address Float Delay	TCLAX	80	ns	
TSVLH	Status Valid to ALE High (See Note 1)		15	ns	
TCLLH	CLK Low to ALE Valid (See Note 1)		15	ns	$C_L = 150$ pF
TCHLL	ALE Inactive Delay (See Note 1)		15	ns	
TCLDV	Data Valid Delay	10	110	ns	
TCHDX	Data Hold Time	10		ns	
TCVNV	Control Active Delay (See Note 1)	5	45	ns	
TCVNX	Control Inactive Delay (See Note 1)	10	45	ns	
TCHDTL	Direction Control Active Delay (See Note 1)		50	ns	
TCHDTH	Direction Control Inactive Delay (See Note 1)		30	ns	
TCLGL	$\overline{RQ}$ Active Delay	0	85	ns	$C_L = 100$ pF
TCLGH	$\overline{RQ}$ Inactive Delay		85	ns	Note 5: $C_L = 30$ pF
TCLSRV	SINTR Valid Delay		150	ns	$C_L = 100$ pF
TOLOH	Output Rise Time		20	ns	From 0.8V to 2.0V
TOHOL	Output Fall Time		12	ns	From 2.0V to 0.8V

NOTES: 1. Signal at 8284 or 8288 shown for reference only.
2. Setup requirement for asynchronous signal only to guarantee recognition at next CLK.
3. Aplies only to T3 and TW states.
4. Applies only to T2 state.
5. Applies only if RQ/GT Mode 1 C_L=60pf, 2.7 KΩ pull up to Vcc.

A.C. TESTING INPUT, OUTPUT WAVEFORM

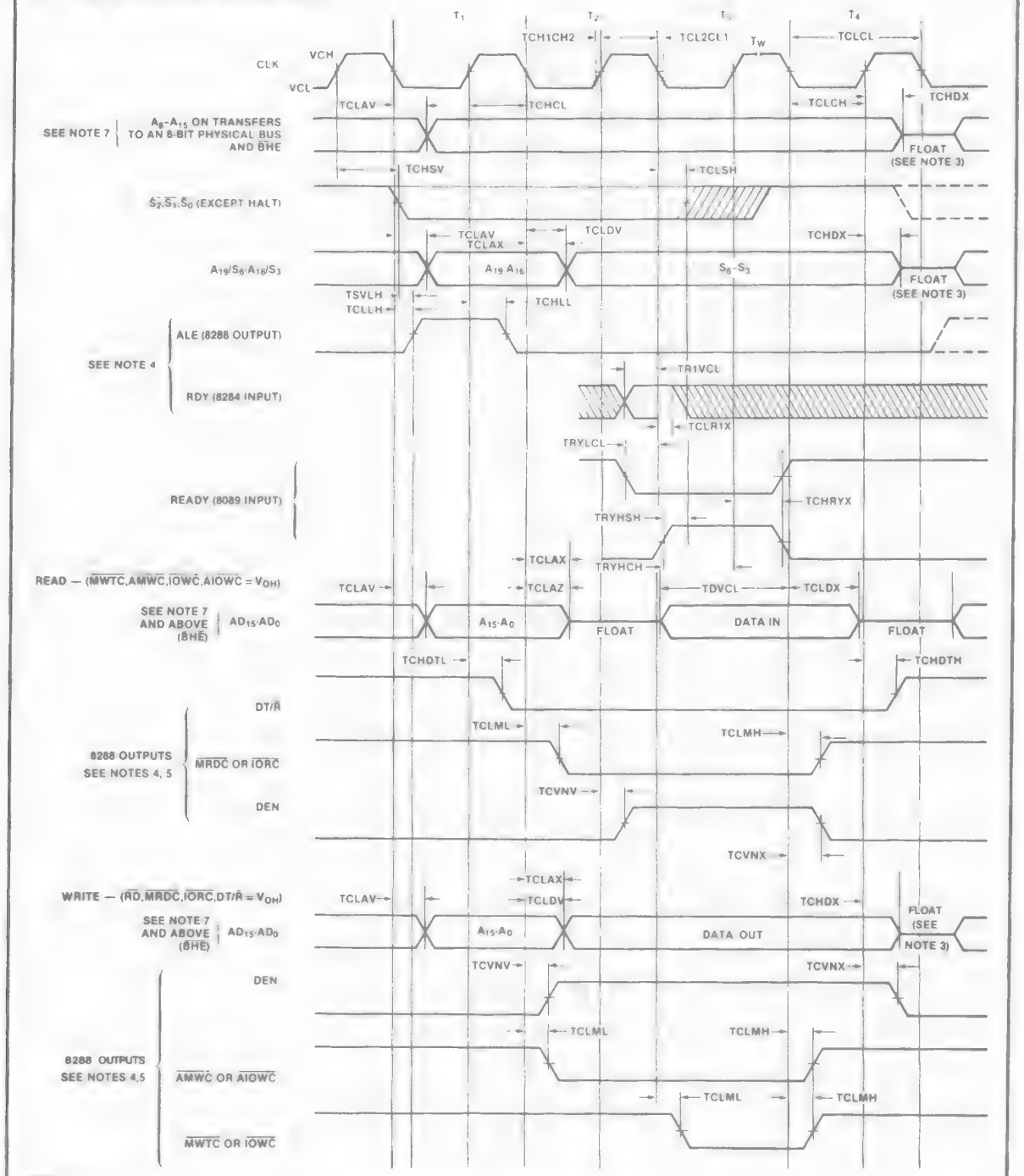


A.C. TESTING LOAD CIRCUIT



WAVEFORMS

8089 BUS TIMING USING 8288

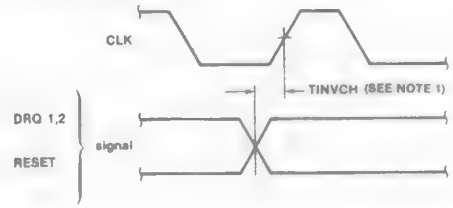


NOTES

1. ALL SIGNALS SWITCH BETWEEN V_{OH} AND V_{OL} UNLESS OTHERWISE SPECIFIED
2. RDY IS SAMPLED NEAR THE END OF T_2, T_3, T_W TO DETERMINE IF T_W MACHINE STATES ARE TO BE INSERTED
3. FOLLOWING A WRITE CYCLE, DATA REMAINS ON THE 8089 LOCAL BUS UNTIL A LOCAL BUS MASTER DECIDES TO RUN ANOTHER BUS CYCLE. THE LOCAL BUS FLOATS BY THE 8089 WHEN THE 8089 ENTERS A REQUEST/GRANT BUS ARBITRATION STATE
4. SIGNALS AT 8284 OR 8288 ARE SHOWN FOR REFERENCE ONLY
5. THE ISSUANCE OF THE 8288 COMMAND AND CONTROL SIGNALS MRDC, MWTC, AMWC, IORC, IOWC, AIOWC, INTA AND DEN, AS A THE ACTIVE HIGH 8288 DEN
6. ALL TIMING MEASUREMENTS ARE MADE AT 1.5V UNLESS OTHERWISE NOTED
7. A_8-A_{15} ARE STABLE ON TRANSFERS TO AN 8-BIT PHYSICAL DATA BUS. IF A_8-A_{15} DON'T FLOAT ON A READ FROM AN 8-BIT PHYSICAL BUS OR MULTIPLEX WITH DATA ON A WRITE TO AN 8-BIT PHYSICAL BUS $\overline{BHE}$ IS STABLE NON MULTIPLEXED FOR ALL TRANSFERS

WAVEFORMS (Continued)

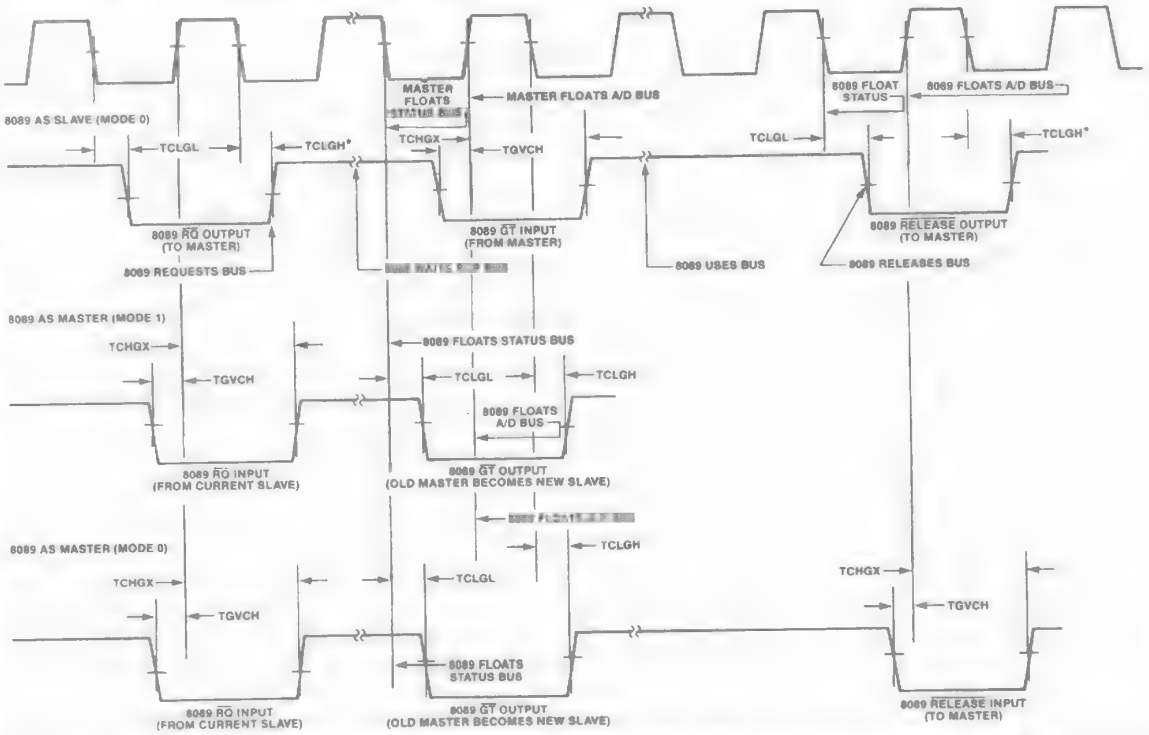
ASYNCHRONOUS SIGNAL RECOGNITION



NOTES:
1. SETUP REQUIREMENTS FOR ASYNCHRONOUS SIGNALS ONLY TO GUARANTEE RECOGNITION AT NEXT CLK.
2. ALL INPUTS EXCEPT CA ARE LATCHED ON A CLK EDGE. THE CA INPUT IS NEGATIVE EDGE TRIGGERED.
3. DRQ BECOMING ACTIVE GREATER THAN 30 ns AFTER THE RISING EDGE OF CLK WILL GUARANTEE NON-RECOGNITION UNTIL THE NEXT RISING CLOCK EDGE.

BUS LOCK SIGNAL TIMING AND SINTR TIMING

REQUEST/GRANT SEQUENCE TIMINGS



*CPU provides active pull-up.

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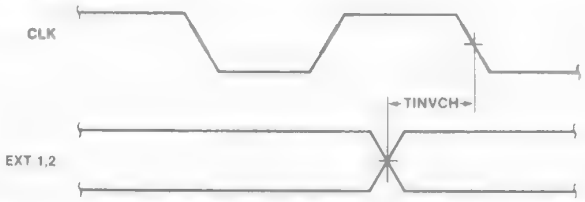
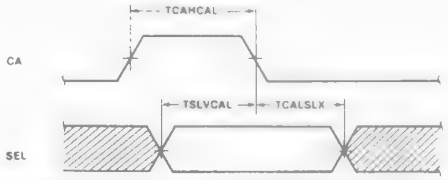
WAVEFORMS (Continued)

EXTERNAL TERMINATE SETUP TIMING



SEL SETUP AND TIMING



8089 INSTRUCTION SET SUMMARY

Data Transfers

POINTER INSTRUCTIONS			OPCODE 7	OPCODE 0 7	OPCODE 0
LPD	P,M	Load Pointer PPP from Addressed Location	P P P 0 0 A A 1	1 0 0 0	1 0 M M
LPDI	P,I	Load Pointer PPP Immediate 4 Bytes	P P P 1 0 0 0 1	0 0 0 0	1 0 0 0
MOVP	M,P	Store Contents of Pointer PPP in Addressed Location	P P P 0 0 A A 1	1 0 0 1	1 0 M M
MOVP	P,M	Restore Pointer	P P P 0 0 A A 1	1 0 0 0	1 1 M M

MOVE DATA				OPCODE 7	OPCODE 0 7	OPCODE 0
MOV	M,M	Move from Source to Destination	Source—	0 0 0 0 0 A A W	1 0 0 1	0 0 M M
			Destination—	0 0 0 0 0 A A W	1 1 0 0	1 1 M M
MOV	R,M	Load Register RRR from Addressed Location		R R R 0 0 A A W	1 0 0 0	0 0 M M
MOV	M,R	Store Contents of Register RRR in Addressed Location		R R R 0 0 A A W	1 0 0 0	0 1 M M
MOVI	R	Load Register RRR Immediate (Byte) Sign Extend		R R R wb 0 0 W	0 0 1 1	0 0 0 0
MOVI	M	Move Immediate to Addressed Location		0 0 0 wb A A W	0 1 0 0	1 1 M M

Control Transfer

CALLS		OPCODE 7	OPCODE 0 7	OPCODE 0
*CALL	Call Unconditional	1 0 0 dd A A W	1 0 0 1	1 1 M M

JUMP		OPCODE 7	OPCODE 0 7	OPCODE 0
JMP	Unconditional	1 0 0 dd 0 0 W	0 0 1 0	0 0 0 0
JZ M	Jump on Zero Memory	0 0 0 dd A A W	1 1 1 0	0 1 M M
JZ R	Jump on Zero Register	R R R dd 0 0 0	0 1 0 0	0 1 0 0
JNZ M	Jump on Non-Zero Memory	0 0 0 dd A A W	1 1 1 0	0 0 M M
JNZ R	Jump on Non-Zero Register	R R R dd 0 0 0	0 1 0 0	0 0 0 0
JBT	Test Bit and Jump if True	B B B dd A A 0	1 0 1 1	1 1 M M
JNBT	Test Bit and Jump if Not True	B B B dd A A 0	1 0 1 1	1 0 M M
JMCE	Mask/Compare and Jump on Equal	0 0 0 dd A A 0	1 0 1 1	0 0 M M
JMCNE	Mask/Compare and Jump on Non-Equal	0 0 0 dd A A 0	1 0 1 1	0 1 M M

Arithmetic and Logic Instructions

INCREMENT, DECREMENT			OPCODE 7	OPCODE 0 7	OPCODE 0
INC	M	Increment Addressed Location	0 0 0 0 0 A A W	1 1 1 0	1 0 M M
INC	R	Increment Register	R R R 0 0 0 0 0	0 0 1 1	1 0 0 0
DEC	M	Decrement Addressed Location	0 0 0 0 0 A A W	1 1 1 0	1 1 M M
DEC	R	Decrement Register	R R R 0 0 0 0 0	0 0 1 1	1 1 0 0

Arithmetic and Logic Instructions

ADD		OPCODE 7	0 7	0
ADDI M,I	ADD Immediate to Memory	0 0 0 wb A A W	1 1 0 0 0 0 M M	
ADDI R,I	ADD Immediate to Register	R R R wb 0 0 W	0 0 1 0 0 0 0 0	
ADD M,R	ADD Register to Memory	R R R 0 0 A A W	1 1 0 1 0 0 M M	
ADD R,M	ADD Memory to Register	R R R 0 0 A A W	1 0 1 0 0 0 M M	

AND		OPCODE	
ANDI M,I	AND Memory with Immediate	0 0 0 wb A A W	1 1 0 0 1 0 M M
ANDI R,I	AND Register with Immediate	R R R wb 0 0 W	0 0 1 0 1 0 0 0
AND M,R	AND Memory with Register	R R R 0 0 A A W	1 1 0 1 1 0 M M
AND R,M	AND Register with Memory	R R R 0 0 A A W	1 0 1 0 1 0 M M

OR		OPCODE	
ORI M,I	OR Memory with Immediate	0 0 0 wb A A W	1 1 0 0 0 1 M M
ORI R,I	OR Register with Immediate	R R R wb A A W	0 0 1 0 0 1 0 0
OR M,R	OR Memory with Register	R R R 0 0 A A W	1 1 0 1 0 1 M M
OR R,M	OR Register with Memory	R R R 0 0 A A W	1 0 1 0 0 1 M M

NOT		OPCODE	
NOT R	Complement Register	R R R 0 0 0 0 0	0 0 1 0 1 1 0 0
NOT M	Complement Memory	0 0 0 0 0 A A W	1 1 0 1 1 1 M M
NOT R,M	Complement Memory, Place in Register	R R R 0 0 A A W	1 0 1 0 1 1 M M

Bit Manipulation and Test Instructions

BIT MANIPULATION		OPCODE 7	0 7	0
SET	Set the Selected Bit	B B B 0 0 A A 0	1 1 1 1 0 1 M M	
CLR	Clear the Selected Bit	B B B 0 0 A A 0	1 1 1 1 1 0 M M	

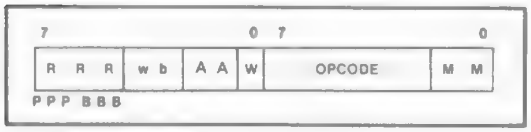
TEST		OPCODE	
TSL	Test and Set Lock	0 0 0 1 1 A A 0	1 0 0 1 0 1 M M

Control

Control		OPCODE 7	07	0
HLT	Halt Channel Execution	0 0 1 0 0 0 0 0	0 1 0 0 1 0 0 0	
SINTR	Set Interrupt Service Flip Flop	0 1 0 0 0 0 0 0	0 0 0 0 0 0 0 0	
NOP	No Operation	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	
XFER	Enter DMA Transfer	0 1 1 0 0 0 0 0	0 0 0 0 0 0 0 0	
WID	Set Source, Destination Bus Width; S,D 0 = 8, 1 = 16	1 S D 0 0 0 0 0	0 0 0 0 0 0 0 0	

*AAField in call instruction can be 00, 01, 10 only.
**OPCODE is second byte fetched.

All instructions consist of at least 2 bytes, while some instructions may use up to 3 additional bytes to specify literals and displacement data. The definition of the various fields within each instruction is given below:



MM	Base Pointer Select
00	GA
01	GB
10	GC
11	PP

RRR Register Field

The RRR field specifies a 16-bit register to be used in the instruction. If GA, GB, GC or TP, are referenced by the RRR field, the upper 4 bits of the registers are loaded with the sign bit (Bit 15). PPP registers are used as 20-bit address pointers.

RRR			
000	r0	GA	
001	r1	GB	
010	r2	GC	
011	r3	BC	; byte count
100	r4	TP	; task block
101	r5	IX	; index register
110	r6	CC	; channel control (mode)
111	r7	MC	; mask/compare

PPP			
000	p0	GA	;
001	p1	GB	;
010	p2	GC	:
100	p4	TP	; task block pointer

NOTES:

BBB Bit Select Field

The bit select field replaces the RRR field in bit manipulation instructions and is used to select a bit to be operated on by those instructions. Bit 0 is the least significant bit.

wb

01 1 byte literal
10 2 byte (word) literal

dd

01 1 byte displacement
10 2 byte (word) displacement.

AA Field

00 The selected pointer contains the operand address.
01 The operand address is formed by adding an 8-bit, unsigned, offset contained in the instruction to the selected pointer. The contents of the pointer are unchanged.
10 The operand address is formed by adding the contents of the Index register to the selected pointer. Both registers remain unchanged.
11 Same as 10 except the Index register is post auto-incremented (by 1 for 8-bit transfer, by 2 for 16-bit transfer).

W Width Field

0 The selected operand is 1 byte long.
1 The selected operand is 2 bytes long.

Additional Bytes

OFFSET : 8-bit unsigned offset.
SDISP : 8/16-bit signed displacement.
LITERAL : 8/16-bit literal. (32 bits for LDPI).

The order in which the above optional bytes appear in IOP instructions is given below:

Offsets are treated as unsigned numbers. Literals and displacements are sign extended (2's complement).

PRELIMINARY

iAPX 86/20
iAPX 88/20
NUMERIC DATA PROCESSOR

8087-3

- **High Performance 2-Chip Numeric Data Processor**
- **Standard iAPX 86/10, 88/10 Instruction Set Plus Arithmetic, Trigonometric, Exponential, and Logarithmic Instructions For All Data Types**
- **All 24 iAPX 86/10, 88/10 Addressing Modes Available**
- **Conforms To Proposed IEEE Floating Point Standard**
- **Support 8 Data Types: 8-, 16-, 32-, 64-Bit Integers, 32-, 64-, 80-Bit Floating Point, and 18-Digit BCD Operands**
- **8x80-Bit Individually Addressable Register Stack plus 14 General Purpose Registers**
- **7 Built-in Exception Handling Functions**
- **MULTIBUS System Compatible Interface**

The Intel iAPX 86/20 and iAPX 88/20 are two-chip numeric data processors (NDP's). They provide the instructions and data types needed for high-performance numeric applications. The NDP provides 100 times the performance of an iAPX 86/10, 88/10 CPU alone for numeric processing. The iAPX 86/20 consists of an iAPX 86/10 (16-bit 8086 CPU) and a numeric processor extension (NPX), the 8087. The iAPX 88/20 consists of the NPX in conjunction with the iAPX 88/10 (8-bit 8088 CPU). The NDP conforms to the proposed IEEE Floating Point Standard.

Both components of the iAPX 86/20 and iAPX 88/20 are implemented in N-channel, depletion load, silicon gate technology (HMOS), housed in two 40-pin packages. The iAPX 86/20, 88/20 adds 68 numeric processing instructions to the iAPX 86/10, 88/10 instruction set and eight 80-bit registers to the register set.

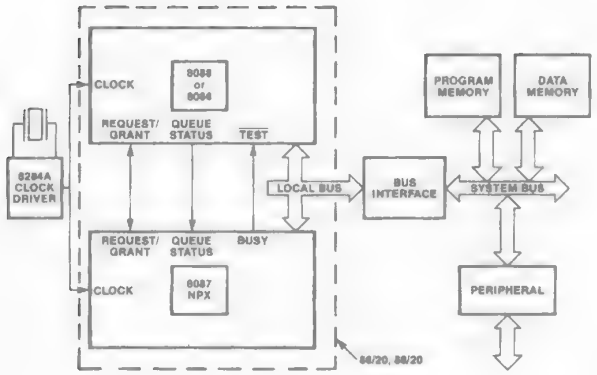


Figure 1. iAPX 86/20, 88/20 Block Diagram

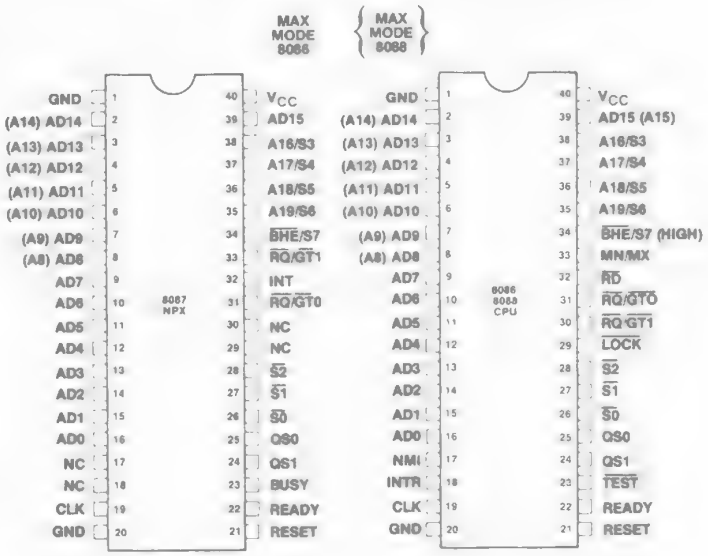


Figure 2. iAPX 86/20, 88/20 Pin Configuration

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Table 1. 8087 Pin Description

Symbol	Type	Name and Function
AD15–AD0	I/O	**Address Data:** These lines constitute the time multiplexed memory address (T_1) and data (T_2, T_3, T_W, T_4) bus. A0 is analogous to $\overline{BHE}$ for the lower byte of the data bus, pins D7–D0. It is LOW during T_1 when a byte is to be transferred on the lower portion of the bus in memory operations. Eight-bit oriented devices tied to the lower half of the bus would normally use A0 to condition chip select functions. These lines are active HIGH. They are input/output lines for 8087 driven bus cycles and are inputs which the 8087 monitors when the 8086/8088 is in control of the bus. A15-A8 do not require an address latch in an iAPX 88/20. The 8087 will supply an address for the T_1-T_4 period.
A19/S6, A18/S5, A17/S4, A16/S3	I/O	**Address Memory:** During T_1 these are the four most significant address lines for memory operations. During memory operations, status information is available on these lines during T_2, T_3, T_W, and T_4. For 8087 controlled bus cycles, S6, S4, and S3 are reserved and currently one (HIGH), while S5 is always LOW. These lines are inputs which the 8087 monitors when the 8086/8088 is in control of the bus.
BHE/S7	I/O	**Bus High Enable:** During T_1 the bus high enable signal ($\overline{BHE}$) should be used to enable data onto the most significant half of the data bus, pins D15–D8. Eight-bit oriented devices tied to the upper half of the bus would normally use $\overline{BHE}$ to condition chip select functions. $\overline{BHE}$ is LOW during T_1 for read and write cycles when a byte is to be transferred on the high portion of the bus. The S7 status information is available during T_2, T_3, T_W, and T_4. The signal is active LOW. S7 is an input which the 8087 monitors during 8086/8088 controlled bus cycles.
$\overline{S2}$, $\overline{S1}$, $\overline{S0}$	I/O	**Status:** For 8087 driven bus cycles, these status lines are encoded as follows: $\overline{S2}$ $\overline{S1}$ $\overline{S0}$ 0 (LOW) X X Unused 1 (HIGH) 0 0 Unused 1 0 1 Read Memory 1 1 0 Write Memory 1 1 1 Passive Status is driven active during T_4, remains valid during T_1 and T_2, and is returned to the passive state (1, 1, 1) during T_3 or during T_W when READY is HIGH. This status is used by the 8288 Bus Controller to generate all memory access control signals. Any change in $\overline{S2}$, $\overline{S1}$, or $\overline{S0}$ during T_4 is used to indicate the beginning of a bus cycle, and the return to the passive state in T_3 or T_W is used to indicate the end of a bus cycle. These signals are monitored by the 8087 when the 8086/8088 is in control of the bus.
$\overline{RQ}/\overline{GT0}$	I/O	**Request/Grant:** This request/grant pin is used by the NPX to gain control of the local bus from the CPU for operand transfers or on behalf of another bus master. It must be connected to one of the two processor request/grant pins. The request grant sequence on this pin is as follows: 1. A pulse one clock wide is passed to the CPU to indicate a local bus request by either the 8087 or the master connected to the 8087 $\overline{RQ}/\overline{GT1}$ pin. 2. The 8087 waits for the grant pulse and when it is received will either initiate bus transfer activity in the clock cycle following the grant or pass the grant out on the $\overline{RQ}/\overline{GT1}$ pin in this clock if the initial request was for another bus master. 3. The 8087 will generate a release pulse to the CPU one clock cycle after the completion of the last 8087 bus cycle or on receipt of the release pulse from the bus master on $\overline{RQ}/\overline{GT1}$.

Table 1. 8087 Pin Description (Continued)

Symbol	Type	Name and Function
$\overline{RQ}/\overline{GT}1$	I/O	**Request/Grant:** This request/grant pin is used by another local bus master to force the 8087 to request the local bus. If the 8087 is not in control of the bus when the request is made the request/grant sequence is passed through the 8087 on the $\overline{RQ}/\overline{GT0}$ pin one cycle later. Subsequent grant and release pulses are also passed through the 8087 with a two and one clock delay, respectively, for resynchronization. $\overline{RQ}/\overline{GT}1$ has has an internal pullup resistor, and so may be left unconnected. If the 8087 has control of the bus the request/grant sequence is as follows: 1. A pulse 1 CLK wide from another local bus master indicates a local bus request to the 8087 (pulse 1). 2. During the 8087's next T_4 or T_1 a pulse 1 CLK wide from the 8087 to the requesting master (pulse 2) indicates that the 8087 has allowed the local bus to float and that it will enter the "RQ/GT acknowledge" state at the next CLK. The 8087's control unit is disconnected logically from the local bus during "RQ/GT acknowledge." 3. A pulse 1 CLK wide from the requesting master indicates to the 8087 (pulse 3) that the "RQ/GT" request is about to end and that the 8087 can reclaim the local bus at the next CLK. Each master-master exchange of the local bus is a sequence of 3 pulses. There must be one dead CLK cycle after each bus exchange. Pulses are active LOW.
QS1, QS0	I	**QS1, QS0:** QS1 and QS0 provide the 8087 with status to allow tracking of the CPU instruction queue. **QS1 QS0** 0 (LOW) 0 No Operation 0 1 First Byte of Op Code from Queue 1 (HIGH) 0 Empty the Queue 1 1 Subsequent Byte from Queue
INT	O	**Interrupt:** This line is used to indicate that an unmasked exception has occurred during numeric instruction execution when 8087 interrupts are enabled. This signal is typically routed to an 8259A. INT is active HIGH.
BUSY	O	**Busy:** This signal indicates that the 8087 NEU is executing a numeric instruction. It is connected to the CPU's $\overline{TEST}$ pin to provide synchronization. In the case of an unmasked exception BUSY remains active until the exception is cleared. BUSY is active HIGH.
READY	I	**Ready:** READY is the acknowledgment from the addressed memory device that it will complete the data transfer. The RDY signal from memory is synchronized by the 8284A Clock Generator to form READY. This signal is active HIGH.
RESET	I	**Reset:** RESET causes the processor to immediately terminate its present activity. The signal must be active HIGH for at least four clock cycles. RESET is internally synchronized.
CLK	I	**Clock:** The clock provides the basic timing for the processor and bus controller. It is asymmetric with a 33% duty cycle to provide optimized internal timing.
V_{CC}		**Power:** V_{CC} is the +5V power supply pin.
GND		**Ground:** GND are the ground pins.

NOTE:
For the pin descriptions of the 8086 and 8088 CPU's reference those respective data sheets (iAPX 86/10, iAPX 88/10).

APPLICATION AREAS

The iAPX 86/20 and iAPX 88/20 provide functions meant specifically for high performance numeric processing requirements. Trigonometric, logarithmic, and exponential functions are built into the processor hardware. These functions are essential in scientific, engineering, navigational, or military applications.

The NDP also has capabilities meant for business or commercial computing. An iAPX 86/20, 88/20 can process Binary Coded Decimal (BCD) numbers up to 18 digits without roundoff errors. It can also perform arithmetic on integers as large as 64 bits ($\pm 10^{18}$).

PROGRAMMING LANGUAGE SUPPORT

Programs for the iAPX 86/20 and iAPX 88/20 can be written in ASM-86, the iAPX 86,88 assembly language, PL/M-86, FORTRAN-86, and PASCAL-86, Intel's high-level languages for iAPX 86, 88 systems.

Details

The remainder of the data sheet will concentrate on the numeric processor extension (refered to as NPX or 8087). For iAPX 86/10 or iAPX 88/10 CPU details refer to those respective data sheets.

FUNCTIONAL DESCRIPTION

The iAPX 86/20, 88/20 Numeric Data Processor's architecture is designed for high performance numeric computing in conjunction with general purpose processing.

The 8087 is a numeric processor extension that provides arithmetic and logical instruction support for a variety of numeric data types in iAPX 86/20, 88/20 systems. It also executes numerous built-in transcendental functions (e.g., tangent and log functions). The 8087 executes instructions as a coprocessor to a maximum mode 8086 or 8088. It effectively extends the register and instruction set of an iAPX 86/10 or 88/10 based system and adds several new data types as well. Figure 3 presents the registers of the iAPX 86/20. Table 2 shows the range of data types supported by the NDP. The 8087 is treated as an extension to the iAPX 86/10 or 88/10, providing register, data types, control, and instruction capabilities at the hardware level. At the programmers level the iAPX 86/20, 88/20 is viewed as a single unified processor.

iAPX 86/20, 88/20 System Configuration

As a coprocessor to an 8086 or 8088, the 8087 is wired in parallel with the CPU as shown in Figure 4. The CPU's status ($\overline{S0}$-$\overline{S2}$) and queue status lines (QS0-QS1) enable the 8087 to monitor and decode

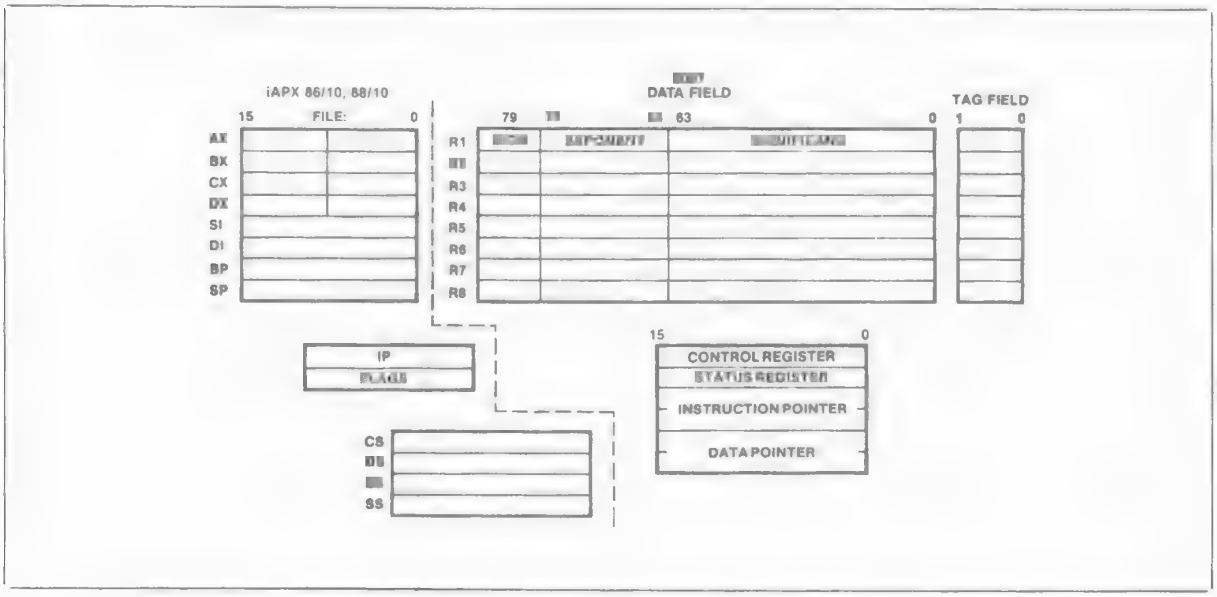


Figure 3. iAPX 86/20 Architecture

Table 2. iAPX 86/20, 88/20 Data Types

Data Formats	Range	Precision	Most Significant Byte (7 0 7 0 7 0 7 0 7 0 7 0 7 0 7 0 7 0 7 0)
Byte Integer	10^2	8 Bits	I_7 I_0 Two's Complement
Word Integer	10^4	16 Bits	I_{15} I_0 Two's Complement
Short Integer	10^9	32 Bits	I_{31} I_0 Two's Complement
Long Integer	10^{18}	64 Bits	I_{63} I_0 Two's Complement
Packed BCD	10^{18}	18 Digits	S — $D_{17}D_{16}$ D_1 D_0
Short Real	$10^{\pm 38}$	24 Bits	S E_7 E_0 F_1 F_{23} F_0 Implicit
Long Real	$10^{\pm 308}$	53 Bits	S E_{10} E_0 F_1 F_{52} F_0 Implicit
Temporary Real	$10^{\pm 4932}$	64 Bits	S E_{14} E_0 F_0 F_{63}

Integer: I

Packed BCD: $(-1)^S(D_{17}\ldots D_0)$

Real: $(-1)^S(2^{E-BIAS})(F_0 \cdot F_1 \ldots)$

Bias = 127 for Short Real
1023 for Long Real
16383 for Temp Real

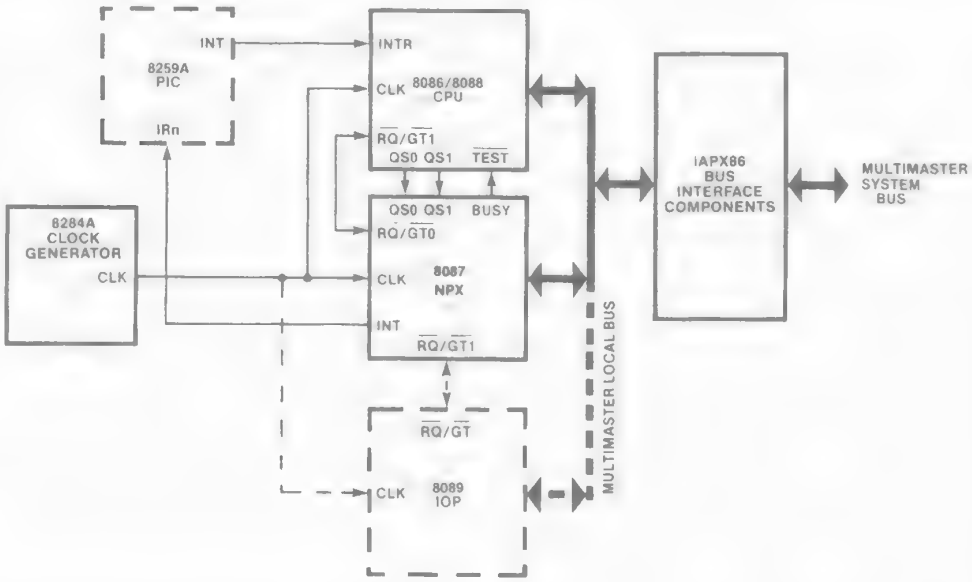


Figure 4. NDP System Configuration

AFN-01820D

instructions in synchronization with the CPU and without any CPU overhead. Once started the 8087 can process in parallel with and independent of the host CPU. For resynchronization, the NPX's BUSY signal informs the CPU that the NPX is executing an instruction and the CPU WAIT instruction tests this signal to insure that the NPX is ready to execute subsequent instructions. The NPX can interrupt the CPU when it detects an error or exception. The 8087's interrupt request line is typically routed to the CPU through an 8259A Programmable Interrupt Controller. (See Figure 2 for 8087 pinout information.)

The 8087 uses one of the request/grant lines of the iAPX 86, 88 architecture (typically $\overline{RQ}/\overline{GT1}$) to obtain control of the local bus for data transfers. The other request/grant line is available for general system use (for instance by an I/O processor in LOCAL mode). A bus master can also be connected to the 8087's $\overline{RQ}/\overline{GT1}$ line. In this configuration the 8087 will pass the request/grant handshake signals between the CPU and the attached master when the 8087 is not in control of the bus and will relinquish the bus to the master directly when the 8087 is in control. In this way two additional masters can be configured in an iAPX 86/20, 88/20 system; one will share the 8086 bus with the 8087 on a first come first served basis, and the second will be guaranteed to be higher in priority than the 8087.

As Figure 4 shows, all processors utilize the same clock generator and system bus interface components (bus controller, latches, transceivers and bus arbiter).

Bus Operation

The 8087 bus structure, operation and timing are identical to all other processors in the iAPX 86, 88 series (maximum mode configuration). The address is time multiplexed with the data on the first 16/8 lines of the address/data bus. A16 through A19 are time multiplexed with four status lines S3–S6. S3, S4 and S6 are always one (high) for 8087 driven bus cycles while S5 is always zero (low). When the 8087 is monitoring CPU bus cycles (passive mode) S6 is also monitored by the 8087 to differentiate 8086/8088 activity from that of a local I/O processor or any other local bus master. (The 8086/8088 must be the only processor on the local bus to drive S6 low.) S7 is multiplexed with and has the same value as $\overline{BHE}$ for all 8087 bus cycles.

The first three status lines, $\overline{S0}$-$\overline{S2}$, are used with an 8288 bus controller to determine the type of bus cycle being run:

$\overline{S2}$	$\overline{S1}$	$\overline{S0}$	
0	X	X	Unused
1	0	0	Unused
1	0	1	Memory Data Read
1	1	0	Memory Data Write
1	1	1	Passive (no bus cycle)

Programming Interface

The NDP includes the standard iAPX 86/10, 88/10 instruction set for general data manipulation and program control. It also includes 68 numeric instructions for extended precision integer, floating point, trigonometric, logarithmic, and exponential functions. Sample execution times for several NDP functions are shown in Figure 4. Overall iAPX 86/20 system performance is 100 times that of an iAPX 86/10 class processor for numeric instructions.

Any instruction executed by the NDP is the combined result of the CPU and NPX activity. The CPU and the NPX have specialized functions and registers providing fast concurrent operation. The CPU controls overall program execution while the NPX uses the coprocessor interface to recognize and perform numeric operations.

Table 2 lists the eight data types the iAPX 86/20, 88/20 supports and presents the format for each type. Internally, the NPX holds all numbers in the temporary real format. Load and store instructions automatically convert operands represented in memory as 16-, 32-, or 64-bit integers, 32- or 64-bit floating point numbers or 18-digit packed BCD numbers into temporary real format and vice versa. The NDP also provides the capability to control round off, underflow, and overflow errors in each calculation.

Computations in the NPX use the processor's register stack. These eight 80-bit registers provide the equivalent capacity of 20 32-bit registers. The NPX register set can be accessed as a stack, with instructions operating on the top one or two stack elements, or as a fixed register set, with instructions operating on explicitly designated registers.

Table 5 lists the 8087's instructions by class. All appear as ESCAPE instructions to the host. Assembly language programs are written in ASM-86, the iAPX 86, 88 assembly language. Table 3 gives the execution times of some typical numeric instructions.

Table 3. Execution Times for Selected iAPX 86/20 Numeric Instructions and Corresponding iAPX 86/10 Emulation

Floating Point Instruction	Approximate Execution Time (μs)	
	iAPX 86/20 (5 MHz Clock)	iAPX 86/10 Emulation
Add/Subtract	17	1,600
Multiply (single precision)	19	1,600
Multiply (extended precision)	27	2,100
Divide	39	3,200
Compare	9	1,300
Load (double precision)	10	1,700
Store (double precision)	21	1,200
Square Root	36	19,600
Tangent	90	13,000
Exponentiation	100	17,100

NUMERIC PROCESSOR EXTENSION ARCHITECTURE

As shown in Figure 5, the 8087 is internally divided into two processing elements, the control unit (CU) and the numeric execution unit (NEU). The NEU executes all numeric instructions, while the CU receives and decodes instructions, reads and writes memory operands and executes NPX control instructions. The two elements are able to operate independently of one another, allowing the CU to maintain synchronization with the CPU while the NEU is busy processing a numeric instruction.

Control Unit

The CU keeps the 8087 operating in synchronization with its host CPU. 8087 instructions are intermixed with CPU instructions in a single instruction stream. The CPU fetches all instructions from memory; by monitoring the status signals ($\overline{S0}$-$\overline{S2}$, S6) emitted by the CPU, the NPX control unit determines when an

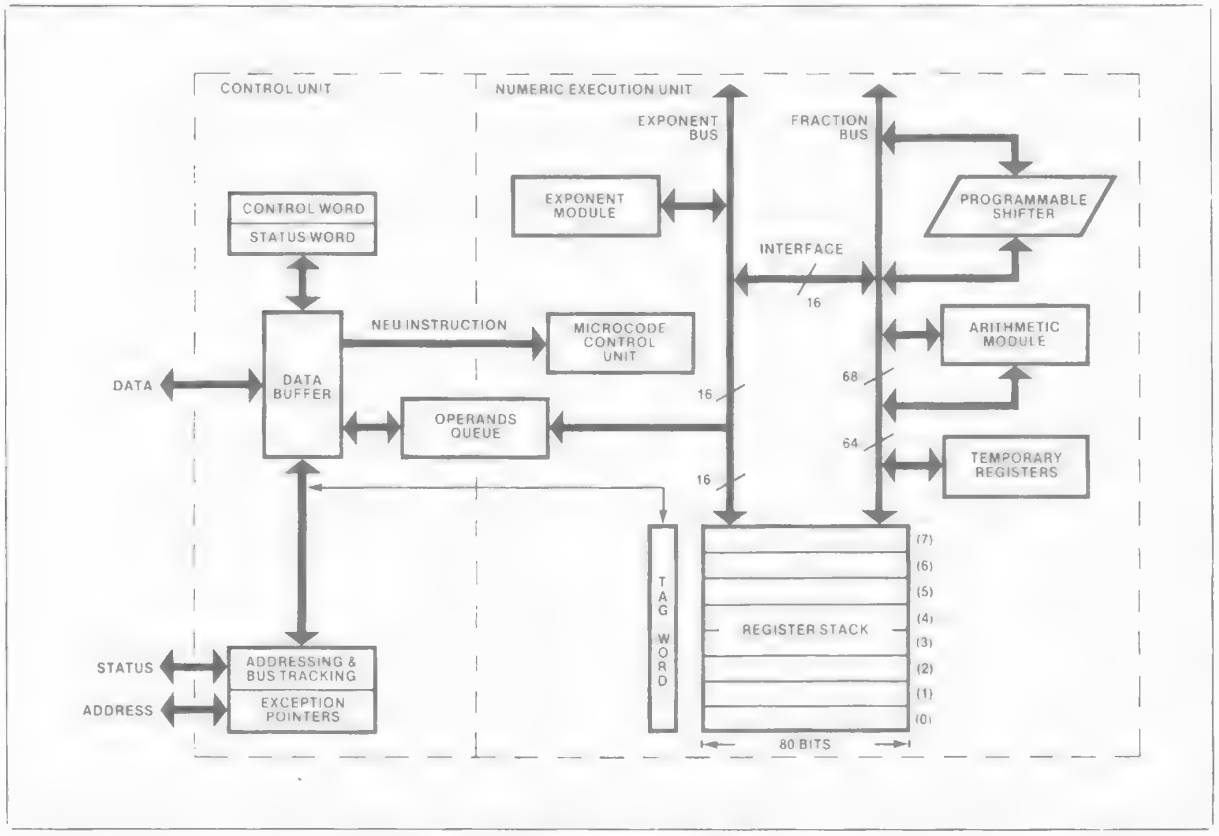


Figure 5. 8087 Block Diagram

8086 instruction is being fetched. The CU monitors the Data bus in parallel with the CPU to obtain instructions that pertain to the 8087.

The CU maintains an instruction queue that is identical to the queue in the host CPU. The CU automatically determines if the CPU is an 8086 or an 8088 immediately after reset (by monitoring the $\overline{BHE}$/ S7 line) and matches its queue length accordingly. By monitoring the CPU's queue status lines (QS0, QS1), the CU obtains and decodes instructions from the queue in synchronization with the CPU.

A numeric instruction appears as an ESCAPE instruction to the 8086 or 8088 CPU. Both the CPU and NPX decode and execute the ESCAPE instruction together. The 8087 only recognizes the numeric instructions shown in Table 5. The start of a numeric operation is accomplished when the CPU executes the ESCAPE instruction. The instruction may or may not identify a memory operand.

The CPU does, however, distinguish between ESC instructions that reference memory and those that do not. If the instruction refers to a memory operand, the CPU calculates the operand's address using any one of its available addressing modes, and then performs a "dummy read" of the word at that location. (Any location within the 1M byte address space is allowed.) This is a normal read cycle except that the CPU ignores the data it receives. If the ESC instruction does not contain a memory reference (e.g. an 8087 stack operation), the CPU simply proceeds to the next instruction.

An 8087 Instruction can have one of three memory reference options; (1) not reference memory; (2) load an operand word from memory into the 8087; or (3) store an operand word from the 8087 into memory. If no memory reference is required, the 8087 simply executes its instruction. If a memory reference is required, the CU uses a "dummy read" cycle initiated by the CPU to capture and save the address that the CPU places on the bus. If the instruction is a load, the CU additionally captures the data word when it becomes available on the local data bus. If data required is longer than one word, the CU immediately obtains the bus from the CPU using the request/grant protocol and reads the rest of the information in consecutive bus cycles. In a store operation, the CU captures and saves the store address as in a load, and ignores the data word that follows in the "dummy read" cycle. When the 8087 is ready to perform the store, the CU obtains the bus from the CPU and writes the operand starting at the specified address.

Numeric Execution Unit

The NEU executes all instructions that involve the register stack; these include arithmetic, logical, transcendental, constant and data transfer instructions. The data path in the NEU is 84 bits wide (68 fraction bits, 15 exponent bits and a sign bit) which allows internal operand transfers to be performed at very high speeds.

When the NEU begins executing an instruction, it activates the 8087 BUSY signal. This signal can be used in conjunction with the CPU WAIT instruction to resynchronize both processors when the NEU has completed its current instruction.

Register Set

The iAPX 86/20 register set is shown in Figure 3. Each of the eight data registers in the 8087's register stack is 80 bits wide and is divided into "fields" corresponding to the NDP's temporary real data type.

At a given point in time the TOP field in the control word identifies the current top-of-stack register. A "push" operation decrements TOP by 1 and loads a value into the new top register. A "pop" operation stores the value from the current top register and then increments TOP by 1. Like iAPX 86/10, 88/10 stacks in memory, the 8087 register stack grows "down" toward lower-addressed registers.

Instructions may address the data registers either implicitly or explicitly. Many instructions operate on the register at the top of the stack. These instructions implicitly address the register pointed to by the TOP. Other instructions allow the programmer to explicitly specify the register which is to be used. Explicit register addressing is "top-relative."

Status Word

The status word shown in Figure 6 reflects the overall state of the 8087; it may be stored in memory and then inspected by CPU code. The status word is a 16-bit register divided into fields as shown in Figure 6. The busy bit (bit 15) indicates whether the *NEU* is either executing an instruction or has an interrupt request pending (B = 1), or is idle (B = 0). Several instructions which store and manipulate the status word are executed exclusively by the CU, and these do not set the busy bit themselves.

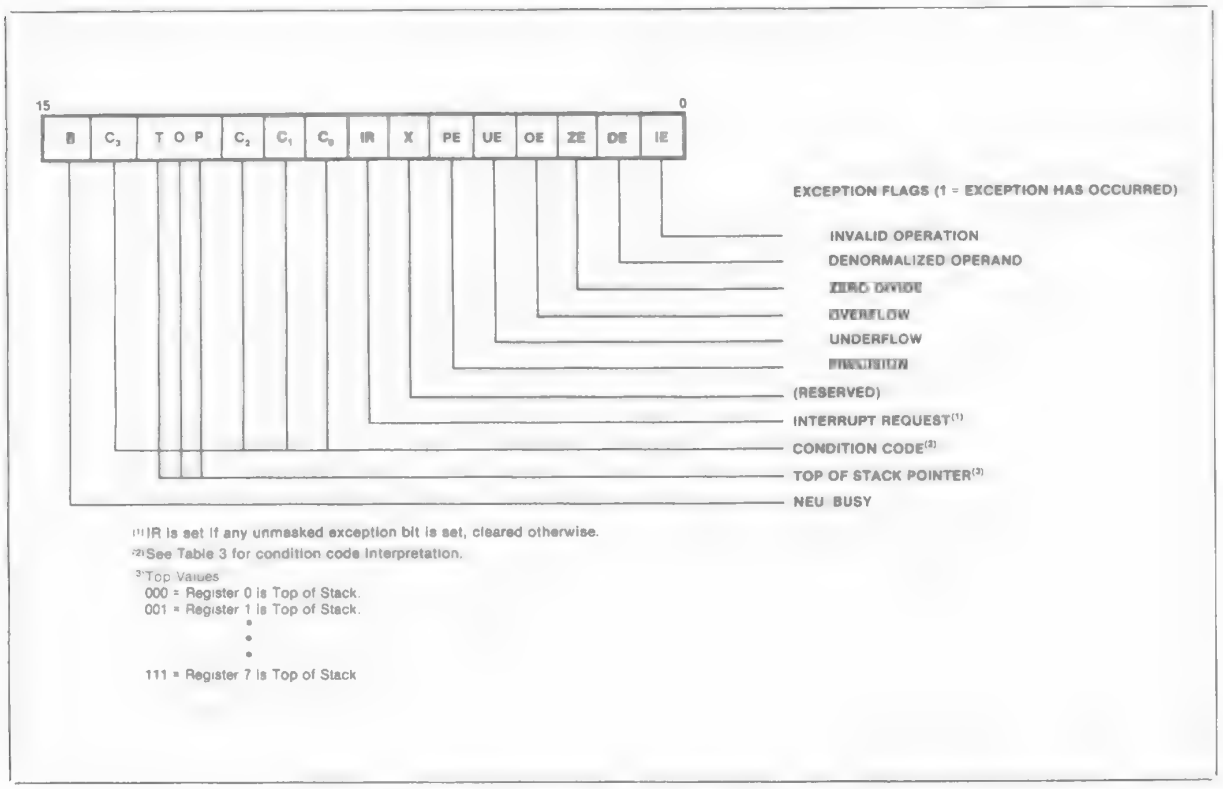


Figure 6. 8087 Status Word

The four numeric condition code bits (C_0–C_3) are similar to the flags in a CPU: various instructions update these bits to reflect the outcome of NDP operations. The effect of these instructions on the condition code bits is summarized in Table 4.

Bits 14–12 of the status word point to the 8087 register that is the current top-of-stack (TOP) as described above.

Bit 7 is the interrupt request bit. This bit is set if any unmasked exception bit is set and cleared otherwise.

Bits 5–0 are set to indicate that the NEU has detected an exception while executing an instruction.

Tag Word

The tag word marks the content of each register as shown in Figure 7. The principal function of the tag word is to optimize the NDP's performance. The tag word can be used, however, to interpret the contents of 8087 registers.

Instruction and Data Pointers

The instruction and data pointers (see Figure 8) are provided for user-written error handlers. Whenever the 8087 executes an NEU instruction, the CU saves the instruction address, the operand address (if present) and the instruction opcode. 8087 instructions can store this data into memory.

Table 4. Condition Code Interpretation

Instruction	C_3	C_2	C_1	C_0	Interpretation
Compare, Test	0	0	X	0	A > B
	0	0	X	1	A < B
	1	0	X	0	A = B
	1	1	X	1	A ? B (not comparable)
Remainder	Q_1	0	Q_0	Q_2	Complete reduction
	Q_1	1	Q_0	Q_2	Incomplete reduction
Examine	0	0	0	0	Valid, positive, unnormalized
	0	0	0	1	Invalid, positive, exponent ≠ 0
	0	0	1	0	Valid, negative, unnormalized
	0	0	1	1	Invalid, negative, exponent ≠ 0
	0	1	0	0	Valid, positive, normalized
	0	1	0	1	Infinity, positive
	0	1	1	0	Valid, negative, normalized
	0	1	1	1	Infinity, negative
	1	0	0	0	Zero, positive
	1	0	0	1	Empty
	1	0	1	0	Zero, negative
	1	0	1	1	Empty
	1	1	0	0	Invalid, positive, exponent = 0
	1	1	0	1	Empty
	1	1	1	0	Invalid, negative, exponent = 0
	1	1	1	1	Empty

X = value is not affected by instruction.
Q = C_0, C_3, C_1 hold 3 LSBs of the quotient generated during a remainder operation.

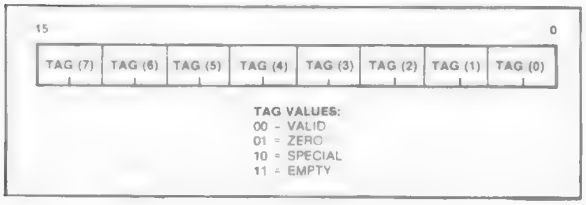


Figure 7. 8087 Tag Word

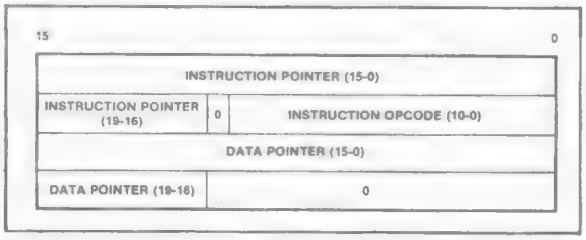


Figure 8. 8087 Instruction and Data Pointers

Control Word

The 8087 provides several processing options which are selected by loading a word from memory into the control word. Figure 9 shows the format and encoding of the fields in the control word.

The low order byte of this control word configures 8087 interrupts and exception masking. Bits 5–0 of the control word contain individual masks for each of the six exceptions that the 8087 recognizes and bit 7 contains a general mask bit for all 8087 interrupts. The high order byte of the control word configures the 8087 operating mode including precision, rounding, and infinity controls. The precision control bits (bits 9–8) can be used to set the 8087 internal operating precision at less than the default of temporary real precision. This can be useful in providing compatibility with earlier generation arithmetic processors of smaller precision than the 8087. The rounding control bits (bits 11–10) provide for directed rounding and true chop as well as the unbiased round to nearest mode specified in the proposed IEEE standard. Control over closure of the number space at infinity is also provided (either affine closure, ±∞, or projective closure, ∞, is treated as unsigned, may be specified).

Exception Handling

The 8087 detects six different exception conditions that can occur during instruction execution. Any or all exceptions will cause an interrupt if unmasked and interrupts are enabled.

If interrupts are disabled the 8087 will simply continue execution regardless of whether the host clears the exception. If a specific exception class is masked and that exception occurs, however, the 8087 will post the exception in the status register and perform an on-chip default exception handling procedure, thereby allowing processing to continue. The exceptions that the 8087 detects are the following:

1. INVALID OPERATION: Stack overflow, stack underflow, indeterminate form (0/0, ∞− ∞, etc.) or the use of a Non-Number (NAN) as an operand. An exponent value is reserved and any bit pattern with this value in the exponent field is termed a Non-Number and causes this exception. If this exception is masked, the 8087's default response is to generate a specific NAN called INDEFINITE, or to propagate already existing NANs as the calculation result.

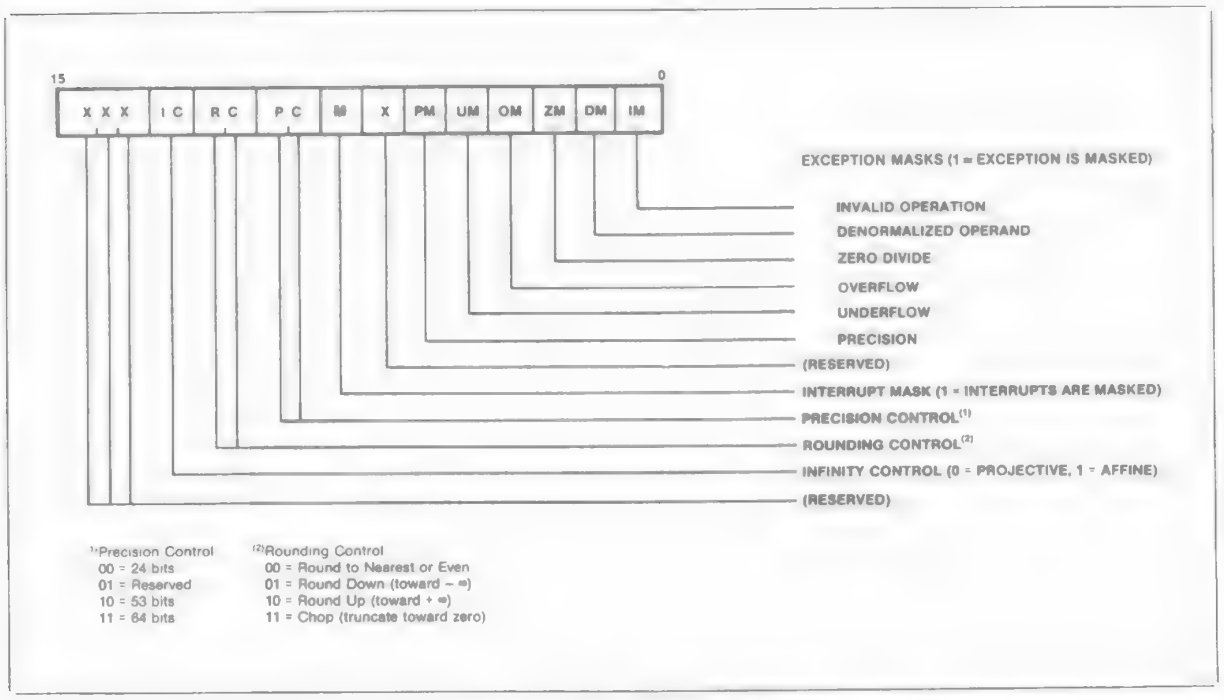


Figure 9. 8087 Control Word

2. OVERFLOW: The result is too large in magnitude to fit the specified format. The 8087 will generate an encoding for infinity if this exception is masked.

3. ZERO DIVISOR: The divisor is zero while the dividend is a non-infinite, non-zero number. Again, the 8087 will generate an encoding for infinity if this exception is masked.

4. UNDERFLOW: The result is non-zero but too small in magnitude to fit in the specified format. If this exception is masked the 8087 will denormalize (shift right) the fraction until the exponent is in range. This process is called gradual underflow.

5. DENORMALIZED OPERAND: At least one of the operands or the result is denormalized; it has the smallest exponent but a non-zero significand. Normal processing continues if this exception is masked off.

6. INEXACT RESULT: If the true result is not exactly representable in the specified format, the result is rounded according to the rounding mode, and this flag is set. If this exception is masked, processing will simply continue.

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias .....0°C to 70°C
Storage Temperature .....−65°C to +150°C
Voltage on Any Pin with
Respect to Ground .....−1.0V to +7V
Power Dissipation .....3.0 Watt

**NOTICE: Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = +5V ±5%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	+0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} +0.5	V	
V_{OL}	Output Low Voltage		0.60	V	I_{OL} = 2.0 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400 μA
I_{CC}	Power Supply Current		475	mA	T_A = 25°C
I_{LI}	Input Leakage Current		±10	μA	0V ≤ V_{IN} ≤ V_{CC}
I_{LO}	Output Leakage Current		±10	μA	0.45V ≤ V_{OUT} ≤ V_{CC}
V_{CL}	Clock Input Low Voltage	−0.5	+0.6	V	
V_{CH}	Clock Input High Voltage	3.9	V_{CC} + 1.0	V	
C_{IN}	Capacitance of Inputs		10	pF	fc = 1 MHz
C_{IO}	Capacitance of I/O Buffer (AD0-15, A_{16}–A_{19}, BHE, S2-S0, RQ/GT) and CLK		15	pF	fc = 1 MHz
C_{OUT}	Capacitance of Outputs BUSY, INT		10	pF	fc = 1 MHz

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = +5V ±5%)

TIMING REQUIREMENTS

Symbol	Parameter	Min.	Max.	Units	Test Conditions
TCLCL	CLK Cycle Period	200	500	ns	
TCLCH	CLK Low Time	(⅔ TCLCL) − 15		ns	
TCHCL	CLK High Time	(⅓ TCLCL) + 2		ns	
TCH1CH2	CLK Rise Time		10	ns	From 1.0V to 3.5V
TCL2CL1	CLK Fall Time		10	ns	From 3.5V to 1.0V
TDVCL	Data In Setup Time	30		ns	
TCLDX	Data In Hold Time	10		ns	
TRYHCH	READY Setup Time	(⅔ TCLCL) − 15		ns	
TCHRYX	READY Hold Time	30		ns	
TRYLCL	READY Inactive to CLK (See Note 3)	−8		ns	
TGVCH	RQ/GT Setup Time	30		ns	
TCHGX	RQ/GT Hold Time	40		ns	
TQVCL	QS0-1 Setup Time	30		ns	
TCLQX	QS0-1 Hold Time	10		ns	
TSACH	Status Active Setup Time	30		ns	
TSNCL	Status Inactive Setup Time	30		ns	
TILIH	Input Rise Time (Except CLK)		20	ns	From 0.8V to 2.0V
TIHIL	Input Fall Time (Except CLK)		12	ns	From 2.0V to 0.8V

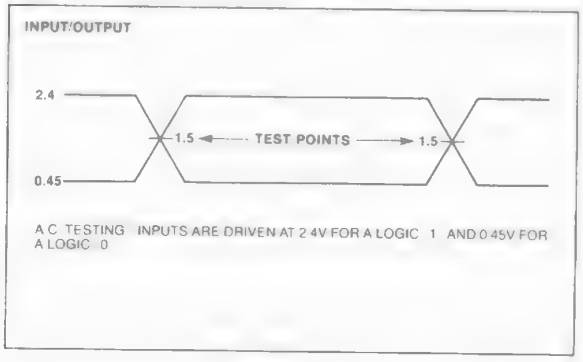
A.C. CHARACTERISTICS (Continued)

TIMING RESPONSES

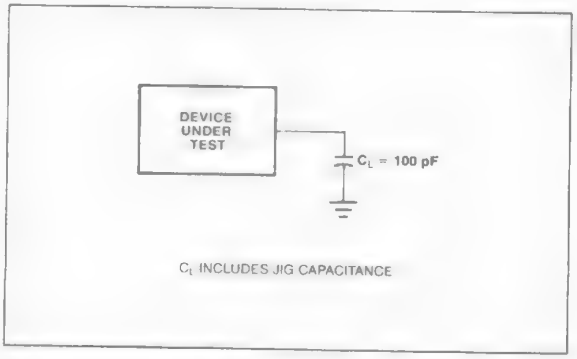
Symbol	Parameter	Min.	Max.	Units	Test Conditions
TCLML	Command Active Delay (See Note 1)	10	35	ns	C_L = 20–100 pF for all 8087 Outputs (in addition to 8087 self-load)
TCLMH	Command Inactive Delay (See Note 1)	10	35	ns	
TRYHSH	Ready Active to Status Passive (See Note 2)		110	ns	
TCHSV	Status Active Delay	10	110	ns	
TCLSH	Status Inactive Delay	10	130	ns	
TCLAV	Address Valid Delay	10	114	ns	
TCLAX	Address Hold Time	10		ns	
TSVLH	Status Valid to ALE High (See Note 1)		15	ns	
TCLLH	CLK Low to ALE Valid (See Note 1)		15	ns	
TCHLL	ALE Inactive Delay (See Note 1)		15	ns	
TCLDV	Data Valid Delay	10	110	ns	
TCHDX	Data Hold Time	10		ns	
TCVNV	Control Active Delay (See Note 1)	5	45	ns	
TCVNX	Control Inactive Delay (See Note 1)	10	45	ns	
TCHBV	BUSY and INT Valid Delay	10	150	ns	
TCHDTL	Direction Control Active Delay (See Note 1)		50	ns	
TCHDTH	Direction Control Inactive Delay (See Note 1)		30	ns	
TCLGL	RQ/GT Active Delay	0	85	ns	C_L = 40 pF (in addition to 8087 self-load)
TCLGH	RQ/GT Inactive Delay	0	85	ns	
TOLOH	Output Rise Time		20	ns	From 0.8V to 2.0V
TOHOL	Output Fall Time		12	ns	From 2.0V to 0.8V

NOTES:
1. Signal at 8284A or 8288 shown for reference only.
2. Applies only to T_3 and wait states.
3. Applies only to T_2 state (8 ns into T_3).

A.C. TESTING INPUT, OUTPUT WAVEFORM

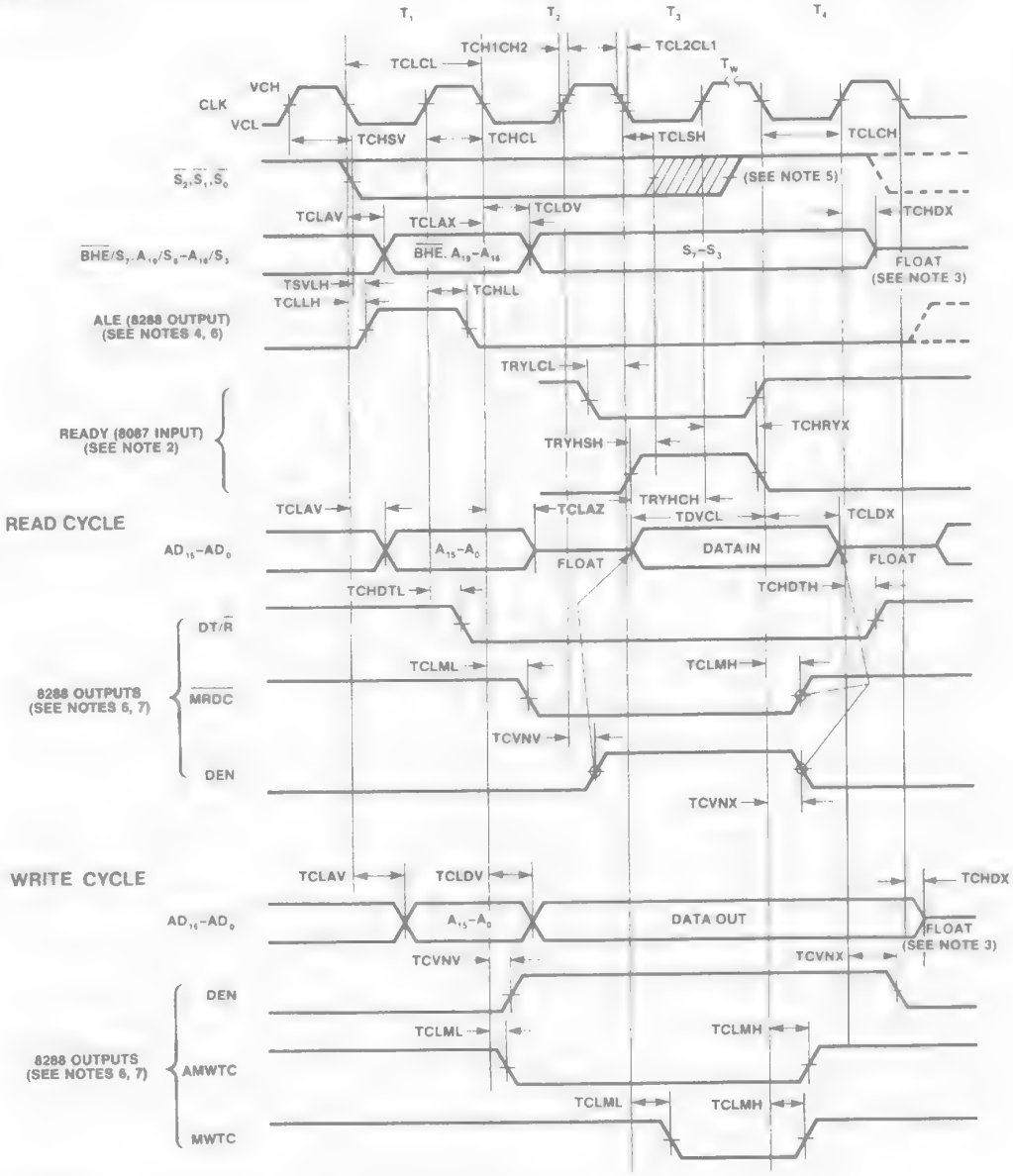


A.C. TESTING LOAD CIRCUIT



WAVEFORMS

MASTER MODE

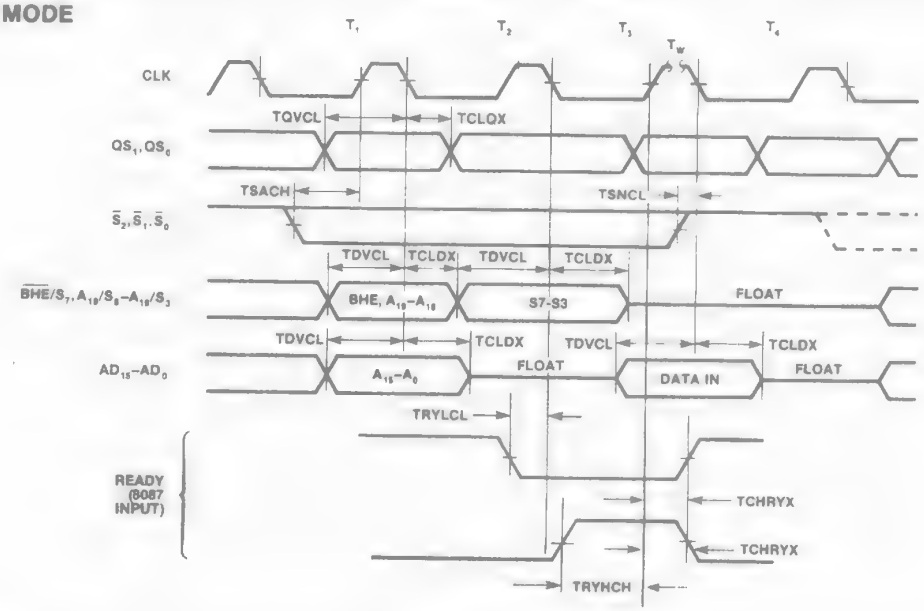


NOTES:

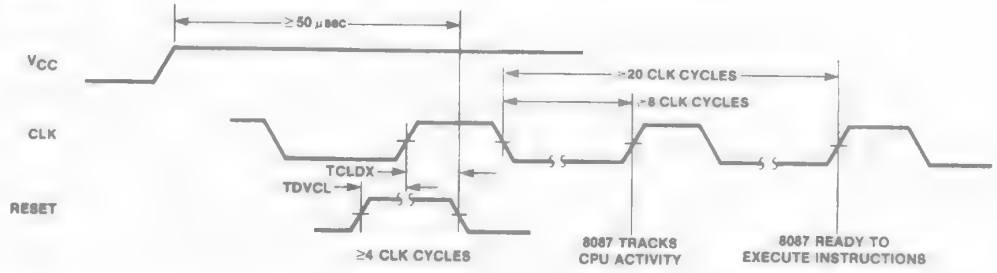
1. ALL SIGNALS SWITCH BETWEEN V_{OL} AND V_{OH} UNLESS OTHERWISE SPECIFIED
2. READY IS SAMPLED NEAR THE END OF T_2, T_3 AND T_W TO DETERMINE IF T_W MACHINE STATES ARE TO BE INSERTED.
3. THE LOCAL BUS FLOATS ONLY IF THE 8087 IS RETURNING CONTROL TO THE 8086/8088
4. ALE RISES AT LATER OF (TSVLH, TCLLH).
5. STATUS INACTIVE IN STATE JUST PRIOR TO T_4
6. SIGNALS AT 8284A OR 8288 ARE SHOWN FOR REFERENCE ONLY.
7. THE ISSUANCE OF 8288 COMMAND AND CONTROL SIGNALS ($\overline{MRDC}$, $\overline{MWTC}$, $\overline{AMWC}$ AND DEN) LAGS THE ACTIVE HIGH 8288 CEN.
8. ALL TIMING MEASUREMENTS ARE MADE AT 1.5V UNLESS OTHERWISE NOTED.

WAVEFORMS (Continued)

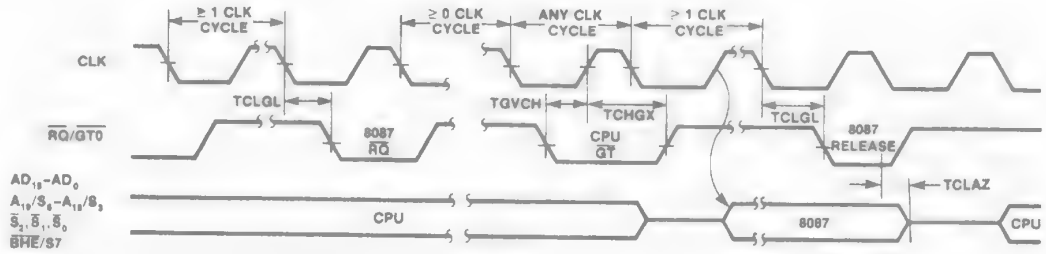
PASSIVE MODE



RESET TIMING



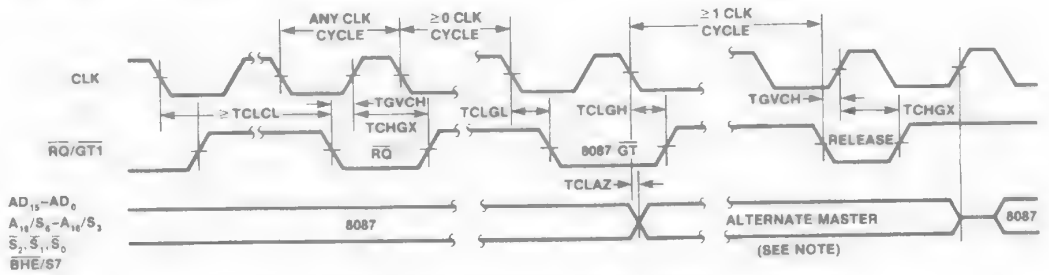
REQUEST/GRANT$_0$ TIMING



NOTE. THE CPU PROVIDES ACTIVE PULLUP OF $\overline{RQ}/\overline{GT0}$. SEE TCLGH SPEC

WAVEFORMS (Continued)

REQUEST/GRANT$_1$ TIMING



NOTE: ALTERNATE MASTER MAY NOT DRIVE THE BUSES OUTSIDE OF THE REGION SHOWN WITHOUT RISKING BUS CONTENTION

BUSY AND INTERRUPT TIMING

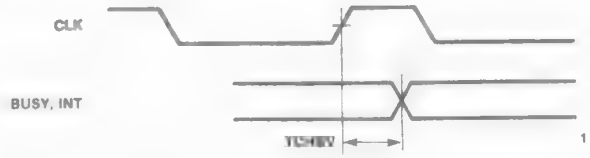


Table 5. 8087 Extensions to the 8086/8088 Instruction Set

	7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0
Data Transfer				
FLD = LOAD				
Integer Real Memory to ST(0)	ESCAPE MF 1	MOD 0 0 0 R/M	(DISP-LO)	(DISP-HI)
Long Integer Memory to ST(0)	ESCAPE 1 1 1	MOD 1 0 1 R/M	(DISP-LO)	(DISP-HI)
Temporary Real Memory to ST(0)	ESCAPE 0 1 1	MOD 1 0 1 R/M	(DISP-LO)	(DISP-HI)
BCD Memory to ST(0)	ESCAPE 1 1 1	MOD 1 0 0 R/M	(DISP-LO)	(DISP-HI)
ST(i) to ST(0)	ESCAPE 0 0 1	1 1 0 0 0 ST(i)		
FST = STORE				
ST(0) to Integer/Real Memory	ESCAPE MF 1	MOD 0 1 0 R/M	(DISP-LO)	(DISP-HI)
ST(0) to ST(i)	ESCAPE 1 0 1	1 1 0 1 0 ST(i)		
FSTP - STORE AND POP				
ST(0) to Integer/Real Memory	ESCAPE MF 1	MOD 0 1 1 R/M	(DISP-LO)	(DISP-HI)
ST(0) to Long Integer Memory	ESCAPE 1 1 1	MOD 1 1 1 R/M	(DISP-LO)	(DISP-HI)
ST(0) to Temporary Real Memory	ESCAPE 0 1 1	MOD 1 1 1 R/M	(DISP-LO)	(DISP-HI)
ST(0) to BCD Memory	ESCAPE 1 1 1	MOD 1 1 0 R/M	(DISP-LO)	(DISP-HI)
ST(0) to ST(i)	ESCAPE 1 0 1	1 1 0 1 1 ST(i)		
FXCH = Exchange ST(i) and ST(0)	ESCAPE 0 0 1	1 1 0 0 1 ST(i)		
Comparison				
FCOM = Compare				
Integer/Real Memory to ST(0)	ESCAPE MF 0	MOD 0 1 0 R/M	(DISP-LO)	(DISP-HI)
ST(i) to ST(0)	ESCAPE 0 0 0	1 1 0 1 0 ST(i)		
FCOMP = Compare and Pop				
Integer/Real Memory to ST(0)	ESCAPE MF 0	MOD 0 1 1 R/M	(DISP-LO)	(DISP-HI)
ST(i) to ST(0)	ESCAPE 0 0 0	1 1 0 1 1 ST(i)		
FCOMPP = Compare ST(1) to ST(0) and Pop Twice	ESCAPE 1 1 0	1 1 0 1 1 0 0 1		
FTST = Test ST(0)	ESCAPE 0 0 1	1 1 1 0 0 1 0 0		
FXAM = Examine ST(0)	ESCAPE 0 0 1	1 1 1 0 0 1 0 1		

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Table 5. 8087 Extensions to the 8086/8088 Instruction Set (Continued)

Arithmetic	7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0
FADD - Addition				
Integer/Real Memory with ST(0)	ESCAPE MF 0	MOD 0 0 0 R/M	(DISP-LO)	(DISP-HI)
ST(i) and ST(0)	ESCAPE d P 0	1 1 0 0 0 STI		
FSUB - Subtraction				
Integer/Real Memory with ST(0)	ESCAPE MF 0	MOD 1 0 R R/M	(DISP-LO)	(DISP-HI)
ST(i) and ST(0)	ESCAPE d P 0	1 1 1 0 R R/M		
FMUL - Multiplication				
Integer/Real Memory with ST(0)	ESCAPE MF 0	MOD 0 0 1 R/M	(DISP-LO)	(DISP-HI)
ST(i) and ST(0)	ESCAPE d P 0	1 1 0 0 1 R/M		
FDIV - Division				
Integer/Real Memory with ST(0)	ESCAPE MF 0	MOD 1 1 R R/M	(DISP-LO)	(DISP-HI)
ST(i) and ST(0)	ESCAPE d P 0	1 1 1 1 R R/M		
FSQRT - Square Root of ST(0)	ESCAPE 0 0 1	1 1 1 1 1 0 1 0		
FSCALE - Scale ST(0) by ST(1)	ESCAPE 0 0 1	1 1 1 1 1 1 0 1		
FPREM - Partial Remainder of ST(0) ÷ ST(1)	ESCAPE 0 0 1	1 1 1 1 1 0 0 0		
FRNDINT - Round ST(0) to Integer	ESCAPE 0 0 1	1 1 1 1 1 1 0 0		
FXTRACT - Extract Components of ST(0)	ESCAPE 0 0 1	1 1 1 1 0 1 0 0		
FABS - Absolute Value of ST(0)	ESCAPE 0 0 1	1 1 1 0 0 0 0 1		
FCHS - Change Sign of ST(0)	ESCAPE 0 0 1	1 1 1 0 0 0 0 0		
Transcendental				
FPTAN - Partial Tangent of ST(0)	ESCAPE 0 0 1	1 1 1 1 0 0 1 0		
FPATAN - Partial Arctangent of ST(0) ÷ ST(1)	ESCAPE 0 0 1	1 1 1 1 0 0 1 1		
F2XM1 - $2^{ST(0)}-1$	ESCAPE 0 0 1	1 1 1 1 0 0 0 0		
FYL2X - $ST(1) \cdot Log_2 [ST(0)]$	ESCAPE 0 0 1	1 1 1 1 0 0 0 1		
FYL2XP1 - $ST(1) \cdot Log_2 [ST(0) + 1]$	ESCAPE 0 0 1	1 1 1 1 1 0 0 1		
Constants				
FLDZ - LOAD + 0.0 into ST(0)	ESCAPE 0 0 1	1 1 1 0 1 1 1 0		
FLD1 - LOAD + 1.0 into ST(0)	ESCAPE 0 0 1	1 1 1 0 1 0 0 0		
FLDPI - LOAD π into ST(0)	ESCAPE 0 0 1	1 1 1 0 1 0 1 1		
FLDL2T - LOAD $\log_2 10$ into ST(0)	ESCAPE 0 0 1	1 1 1 0 1 0 0 1		
FLDL2E - LOAD $\log_2 e$ into ST(0)	ESCAPE 0 0 1	1 1 1 0 1 0 1 0		
FLDLG2 - LOAD $\log_{10} 2$ into ST(0)	ESCAPE 0 0 1	1 1 1 0 1 1 0 0		
FLDLN2 - LOAD $\log_e 2$ into ST(0)	ESCAPE 0 0 1	1 1 1 0 1 1 0 1		

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Table 5. 8087 Extensions to the 8086/8088 Instruction Set (Continued)

	7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0
Processor Control				
FINIT = Initialize NDP	ESCAPE 0 1 1	1 1 1 0 0 0 1 1		
FENI = Enable Interrupts	ESCAPE 0 1 1	1 1 1 0 0 0 0 0		
FDISI = Disable Interrupts	ESCAPE 0 1 1	1 1 1 0 0 0 0 1		
FLDCW = Load Control Word	ESCAPE 0 0 1	MOD 1 0 1 R/M	(DISP-LO)	(DISP-HI)
FSTCW = Store Control Word	ESCAPE 0 0 1	MOD 1 1 1 R/M	(DISP-LO)	(DISP-HI)
FSTSW = Store Status Word	ESCAPE 1 0 1	MOD 1 1 1 R/M	(DISP-LO)	(DISP-HI)
FCLEX = Clear Exceptions	ESCAPE 0 1 1	1 1 1 0 0 0 1 0		
FSTENV = Store Environment	ESCAPE 0 0 1	MOD 1 1 0 R/M	(DISP-LO)	(DISP-HI)
FLDENV = Load Environment	ESCAPE 0 0 1	MOD 1 0 0 R/M	(DISP-LO)	(DISP-HI)
FSAVE = Save State	ESCAPE 1 0 1	MOD 1 1 0 R/M	(DISP-LO)	(DISP-HI)
FRSTOR = Restore State	ESCAPE 1 0 1	MOD 1 0 0 R/M	(DISP-LO)	(DISP-HI)
FINCSTP = Increment Stack Pointer	ESCAPE 0 0 1	1 1 1 1 0 1 1 1		
FDECSTP = Decrement Stack Pointer	ESCAPE 0 0 1	1 1 1 1 0 1 1 0		
FFREE = Free ST(i)	ESCAPE 1 0 1	1 1 0 0 0 ST(i)		
FNOP = No Operation	ESCAPE 0 0 1	1 1 0 1 0 0 0 0		
FWAIT = CPU Wait for NDP	1 0 0 1 1 0 1 1			

FOOTNOTES:

if mod = 00 then DISP = 0*, disp-low and disp-high are absent
if mod = 01 then DISP = disp-low sign-extended to 16-bits, disp-high is absent
if mod = 10 then DISP = disp-high; disp-low
if mod = 11 then r/m is treated as an ST(i) field

if r/m = 000 then EA = (BX) + (SI) + DISP
if r/m = 001 then EA = (BX) + (DI) + DISP
if r/m = 010 then EA = (BP) + (SI) + DISP
if r/m = 011 then EA = (BP) + (DI) + DISP
if r/m = 100 then EA = (SI) + DISP
if r/m = 101 then EA = (DI) + DISP
if r/m = 110 then EA = (BP) + DISP*
if r/m = 111 then EA = (BX) + DISP

*except if mod = 000 and r/m = 110 then EA = disp-high: disp-low.

MF = Memory Format
00 — 32-bit Real
01 — 32-bit Integer
10 — 64-bit Real
11 — 16-bit Integer

ST(0) = Current stack top
ST(i) = i^{th} register below stack top

d = Destination
0 — Destination is ST(0)
1 — Destination is ST(i)

P = Pop
0 — No pop
1 — Pop ST(0)

R = Reverse: When d = 1 reverse the sense of R.
0 — Destination (op) Source
1 — Source (op) Destination

For **FSQRT:** $-0 \le ST(0) \le +\infty$
For **FSCALE:** $-2^{15} \le ST(1) < +2^{15}$ and ST(1) integer
For **F2XM1:** $0 \le ST(0) \le 2^{-1}$
For **FYL2X:** $0 < ST(0) < \infty$
$-\infty < ST(1) < +\infty$
For **FYL2XP1:** $0 \le |ST(0)| < (2 - \sqrt{2})/2$
$-\infty < ST(1) < \infty$
For **FPTAN:** $0 \le ST(0) < \pi/4$
For **FPATAN:** $0 \le ST(0) < ST(1) < +\infty$

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PRELIMINARY

iAPX 86/30
iAPX 88/30
OPERATING SYSTEM PROCESSORS

80130-2

- High-Performance 2-Chip Data Processors Containing Operating System Primitives
- Standard iAPX 86/10, 88/10 Instruction Set Plus Task Management, Interrupt Management, Message Passing, Synchronization and Memory Allocation Primitives
- Fully Extendable To and Compatible With iRMX 86
- Supports Five Operating System Data Types: Jobs, Tasks, Segments, Mailboxes, Regions
- 35 Operating System Primitives
- Built-In Operating System Timers and Interrupt Control Logic Expandable From 8 to 57 Interrupts
- 8086/8087/8088/80186/80188 Compatible At Up To 8 MHz Without Wait States
- MULTIBUS System Compatible Interface

The Intel iAPX 86/30 and iAPX 88/30 are two-chip microprocessors offering general-purpose CPU (8086) instructions combined with real-time operating system support. They provide a foundation for multiprogramming and multitasking applications. The iAPX 86/30 consists of an iAPX 86/10 (16-bit 8086 CPU) and an Operating System Firmware (OSF) component (80130). The 88/30 consists of the OSF and an iAPX 88/10 (8-bit 8088 CPU). (80186 or 80188 CPUs may be used in place of the 8086 or 8088.)

Both components of the 86/30 and 88/30 are implemented in N-channel, depletion-load, silicon-gate technology (HMOS), and are housed in 40-pin packages. The 86/30 and 88/30 provide all the functions of the iAPX 86/10, 88/10 processors plus 35 operating system primitives, hardware support for eight interrupts, a system timer, a delay timer and a baud rate generator.

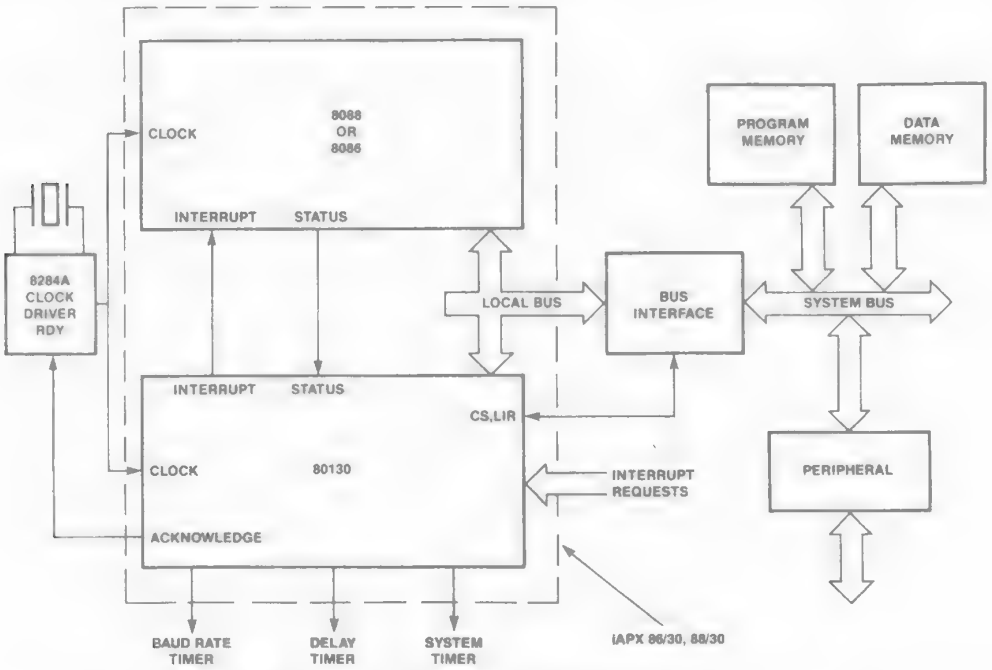


Figure 1. iAPX 86/30, 88/30 Block Diagram

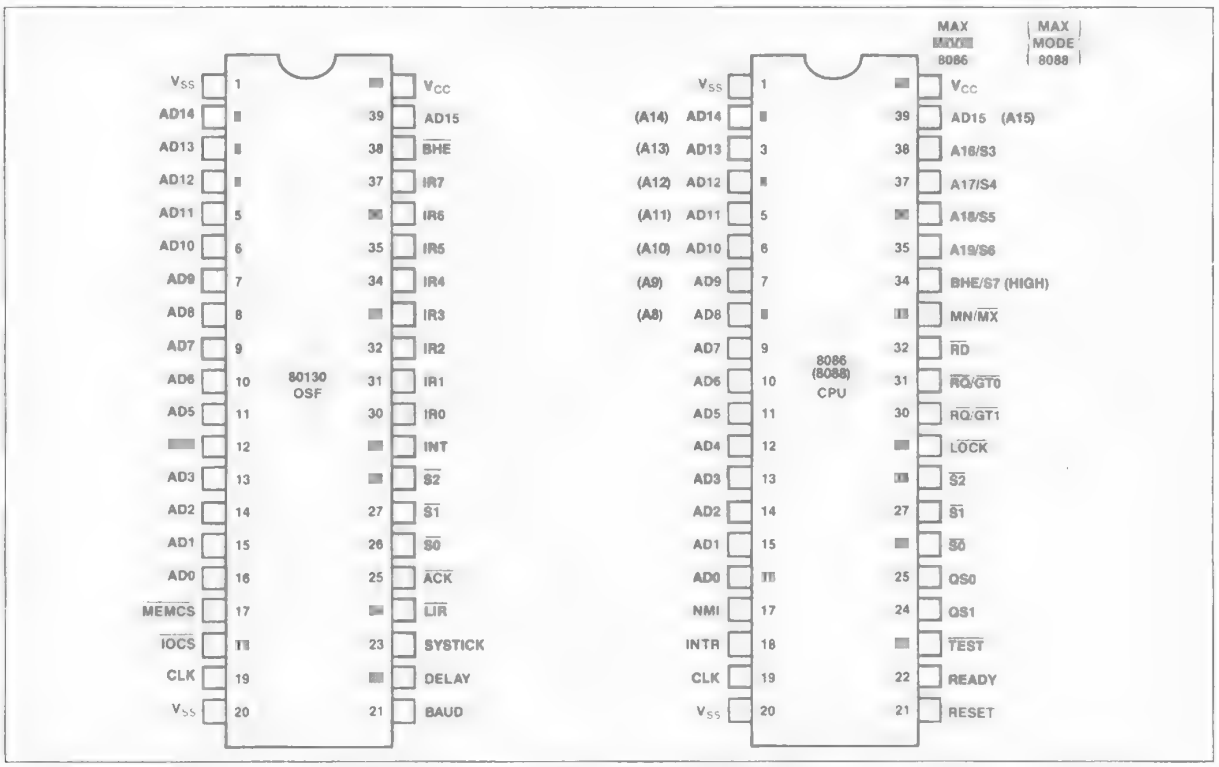


Figure 2. iAPX 86/30, 88/30 Pin Configuration

Table 1. 80130 Pin Description

Symbol	Type	Name and Function
AD_{15}–AD_0	I/O	**Address Data:** These pins constitute the time multiplexed memory address (T_1) and data (T_2, T_3, T_W, T_4) bus. These lines are active HIGH. The address presented during T_1 of a bus cycle will be latched internally and interpreted as an 80130 internal address if MEMCS or IOCS is active for the invoked primitives. The 80130 pins float whenever it is not chip selected, and drive these pins only during T_2–T_4 of a read cycle and T_1 of an INTA cycle.
$\overline{BHE}/S_7$		**Bus High Enable:** The 80130 uses the $\overline{BHE}$ signal from the processor to determine whether to respond with data on the upper or lower data pins, or both. The signal is active LOW. $\overline{BHE}$ is latched by the 80130 on the trailing edge of ALE. It controls the 80130 output data as shown. $\overline{BHE}$ A_0 0 0 Word on AD_{15}–AD_0 0 1 Upper byte on AD_{15}–AD_8 1 0 Lower byte on AD_7–AD_0 1 1 Upper byte on AD_7–AD_0
$\overline{S_2}, \overline{S_1}, \overline{S_0}$	I	**Status:** For the 80130, the status pins are used as inputs only. 80130 encoding follows: $\overline{S_2}$ $\overline{S_1}$ $\overline{S_0}$ 0 0 0 INTA 0 0 1 IORD 0 1 0 IOWR 0 1 1 Passive 1 0 0 Instruction fetch 1 0 1 MEMRD 1 1 X Passive

Table 1. 80130 Pin Description (Continued)

Symbol	Type	Name and Function
CLK	I	**Clock:** The system clock provides the basic timing for the processor and bus controller. It is asymmetric with a 33% duty cycle to provide optimized internal timing. The 80130 uses the system clock as an input to the SYSTICK and BAUD timers and to synchronize operation with the host CPU.
INT	O	**Interrupt:** INT is HIGH whenever a valid interrupt request is asserted. It is normally used to interrupt the CPU by connecting it to INTR.
IR_7–IR_0	I	**Interrupt Requests:** An interrupt request can be generated by raising an IR input (LOW to HIGH) and holding it HIGH until it is acknowledged (Edge-Triggered Mode), or just by a HIGH level on an IR input (Level-Triggered Mode).
$\overline{ACK}$	O	**Acknowledge:** This line is LOW whenever an 80130 resource is being accessed. It is also LOW during the first INTA cycle and second INTA cycle if the 80130 is supplying the interrupt vector information. This signal can be used as a bus ready acknowledgement and/or bus transceiver control.
$\overline{MEMCS}$	I	**Memory Chip Select:** This input must be driven LOW when a kernel primitive is being fetched by the CPU. AD_{13}–AD_0 are used to select the instruction.
$\overline{IOCS}$	I	**Input/Output Chip Select:** When this input is low, during an IORD or IOWR cycle, the 80130's kernel primitives are accessing the appropriate peripheral function as specified by the following table: $\overline{BHE}$ A_3 A_2 A_1 A_0 0 X X X X Passive X X X X 1 Passive X 0 1 X X Passive 1 0 0 X 0 Interrupt Controller 1 1 0 0 0 Systick Timer 1 1 0 1 0 Delay Counter 1 1 1 0 0 Baud Rate Timer 1 1 1 1 0 Timer Control
$\overline{LIR}$	O	**Local Bus Interrupt Request:** This signal is LOW when the interrupt request is for a non-slave input or slave input programmed as being a local slave.
V_{CC}		**Power:** V_{CC} is the +5V supply pin.
V_{SS}		**Ground:** V_{SS} is the ground pin.
SYSTICK	O	**System Clock Tick:** Timer 0 Output. Operating System Clock Reference. SYSTICK is normally wired to IR2 to implement operating system timing interrupt.
DELAY	O	**DELAY Timer:** Output of timer 1. Reserved by Intel Corporation for future use.
BAUD	O	**Baud Rate Generator:** 8254 Mode 3 compatible output. Output of 80130 Timer 2.

FUNCTIONAL DESCRIPTION

The increased performance and memory space of iAPX 86/10 and 88/10 microprocessors have proven sufficient to handle most of today's single-task or single-device control applications with performance to spare, and have led to the increased use of these microprocessors to control *multiple* tasks or devices in real-time. This trend has created a new challenge to designers—development of real-time, multitasking application systems and software. Examples of such systems include control systems that monitor and react to external events in real-time, multifunction desktop and personal computers, PABX equipment which constantly controls the telephone traffic in a multiphone office, file servers/disk subsystems controlling and coordinating multiple disks and multiple disk users, and transaction processing systems such as electronics funds transfer.

The iAPX 86/30, 88/30 Operating System Processors

The Intel® iAPX 86/30, 88/30 Operating System Processors (OSPs) were developed to help solve this

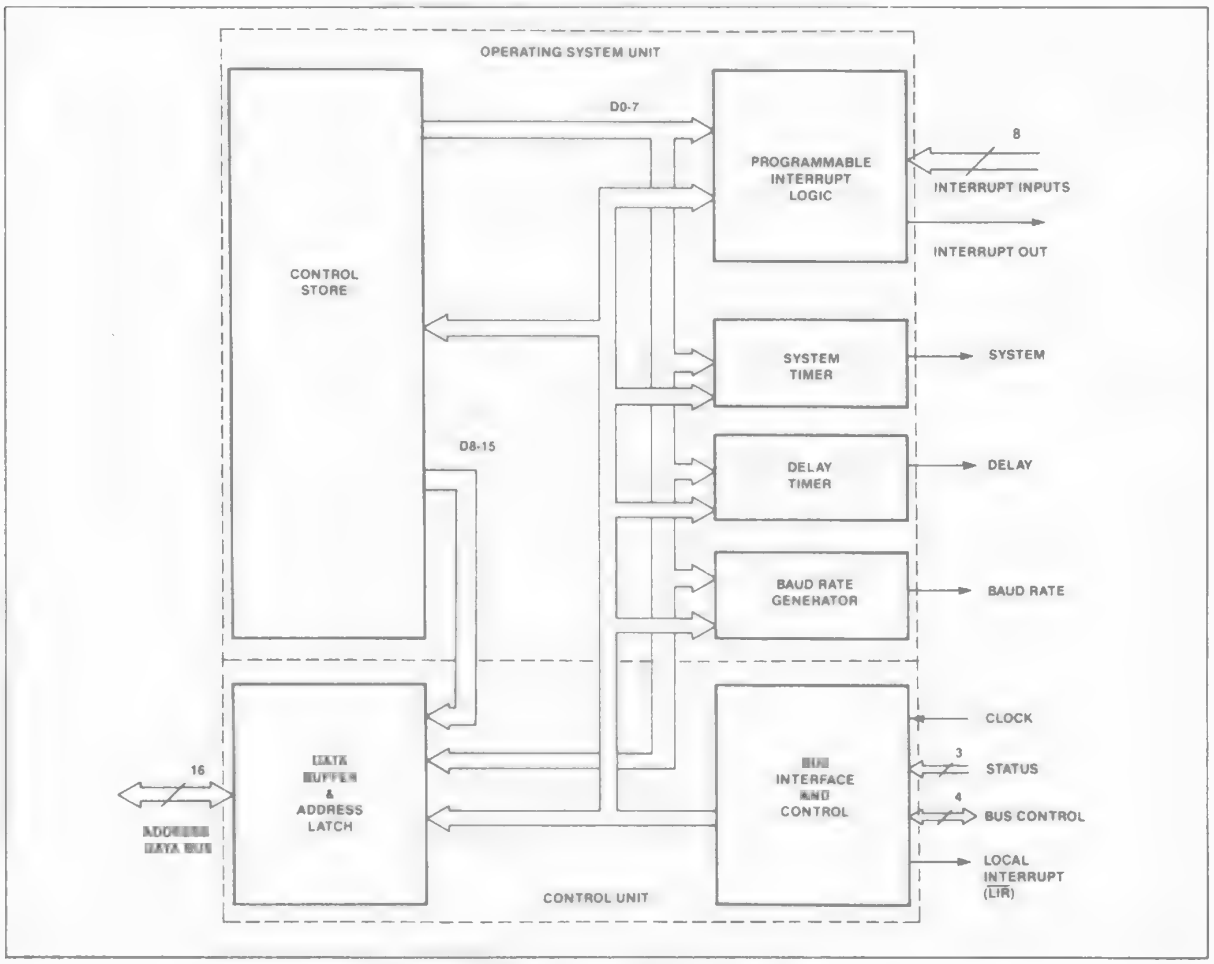


Figure 3. OSF Internal Block Diagram

problem. Their goal is to simplify the design of multitasking application systems by providing a well-defined, fully debugged set of operating system primitives implemented directly in the hardware, thereby removing the burden of designing multitasking operating system primitives from the application programmer.

Both the 86/30 and the 88/30 OSPs are two-chip sets consisting of a main processor, an 8086 or 8088 CPU, and the Intel 80130, Operating System Firmware component (OSF) (see Figure 1). The 80130 provides a set of multitasking kernel primitives, kernel control storage, and the additional support hardware, including system timers and interrupt control, required by these primitives. From the application programmer's viewpoint, the OSF extends the base iAPX 86, 88 architecture by providing 35 operating system primitive instructions, and supporting five new system data types, making the OSF a logical and easy-to-use architectural extension to iAPX 86, 88 system designs.

The OSP Approach

The OSP system data types (SDTs) and primitive instructions allocate, manage and share low-level processor resources in an efficient manner. For example, the OSP implements task context management (managing a task state image consisting of both hardware register set and software control information) for either the basic 86/10 context or the extended 86/20 (8086+8087) numerics context. The OSP manages the entire task state image both while the task is actively executing and while it is inactive. Tasks can be created, put to sleep for specified periods, suspended, executed to perform their functions, and dynamically deleted when their functions are complete.

The Operating System Processors support event-oriented systems designs. Each event may be processed by an individual responding task or along with other closely related events in a common task. External events and interrupts are processed by the OSP interrupt handler primitives using its built-in interrupt controller subsystem as they occur in real-time. The multiple tasks and the multiple events are coordinated by the OSP integral scheduler whose preemptive, priority-based scheduling algorithm and system timers organize and monitor the processing of every task to guarantee that events are processed as they occur in order of relative importance. The 86/30 also provides primitives for intertask communication (by mailboxes) and for mutual exclusion (by regions), essential functions for multitasking applications.

Programming Language Support

Programs for the OSP can be written in ASM 86/88 or PL/M 86/88, Intel's standard system languages for iAPX 86,88 systems.

The Operating System Processor Support Package (iOSP 86) provides an interface library for application programs written in any model of PL/M-86. This library also provides 80130 configuration and initialization support as well as complete user documentation.

OSF PROGRAMMING INTERFACE

The OSF provides 35 operating system kernel primitives which implement multitasking, interrupt management, free memory management, intertask communication and synchronization. Table 4 shows each primitive, and Table 5 gives the execution performance of typical primitives.

OSP primitives are executed by a combination of CPU and OSF (80130) activity. When an OSP primitive is called by an application program task, the iAPX CPU registers and stacks are used to perform the appropriate functions and relay the results to the application programs.

OSP Primitive Calling Sequences

A standard, stack-based, calling sequence is used to invoke the OSF primitives. Before a primitive is called, its operand parameters must be pushed on the task stack. The SI register is loaded with the offset of the last parameter on the stack. The entry code for the primitive is loaded into AX. The primitive invocation call is made with a CPU software interrupt (Table 4). A representative ASM86 sequence for calling a primitive is shown in Figure 4. In PL/M the OSP programmer uses a call to invoke the primitive.

```
                    SAMPLE ASSEMBLY LANGUAGE PRIMITIVE CALL

PUSH P1                          ;PUSH PARAMETER 1
PUSH P2                          ;PUSH PARAMETER 2
  .                              ;  .  .  .
  .                              ;  .  .  .
  .                              ;  .  .  .
PUSH PN                          ;PUSH PARAMETER N
PUSH BP                          ;STACK CALLING CONVENTION
MOV BP,SP
LEA SI,SS:NUM_BYTES_PARAM - 2(BP)
                                 ;SS:SI POINTS TO FIRST
                                 ;PARAMETER ON STACK
MOV AX, ENTRY CODE               ;AX SETS PRIMITIVE ENTRY CODE
INT 184                          ;OSF INTERRUPT

                    OSP PRIMITIVE INVOKED

POP BP
RET NUM_BYTES_PARAM_             ;POP PARAMETERS
                                 ;CX CONTAINS EXCEPTION CODES
                                 ;DL CONTAINS PARAMETER NUMBER
                                 ;   THAT CAUSED EXCEPTION (IF
                                 ;   CX IS NON ZERO)
                                 ;AX CONTAINS WORD RETURN VALUE
                                 ;ES:BX CONTAINS POINTER
                                 ;   RETURN VALUE
```

Figure 4. ASM/86 OSP Calling Convention

OSP Functional Description

Each major function of the OSP is described below. These are:

- Job and Task Management
- Interrupt Management
- Free Memory Management
- Intertask Communication
- Intertask Synchronization
- Environmental Control

The system data types (or SDTs) supported by the OSP are capitalized in the description. A short description of each SDT appears in Table 2.

JOB and TASK Management

Each OSP JOB is a controlled environment in which the applications program executes and the OSF system data types reside. Each individual application program is normally a separate OSP JOB, whether it has one initial task (the minimum) or multiple tasks. JOBs partition the system memory into pools. Each memory pool provides the storage areas in which the OSP will allocate TASK state images and other system data types created by the executing TASKs, and free memory for TASK working space. The OSP supports multiple executing TASKs within a JOB by managing the resources used by each, including the CPU registers, NPX registers, stacks, the system data types, and the available free memory space pool.

When a TASK is created, the OSP allocates memory (from the free memory of its JOB environment) for the TASK's stack and data area and initializes the additional TASK attributes such as the TASK priority level and its error handler location. (As an option, the caller of CREATE TASK may assign previously defined stack and data areas to the TASK.) Task priorities are integers between 0 and 255 (the lower the priority number the higher the scheduling priority of the TASK). Generally, priorities up to 128 will be assigned to TASKs which are to process interrupts. Priorities above 128 do not cause interrupts to be disabled, these priorities (129 to 255) are appropriate for non-interrupt TASKs. If an 8087 Numerics Processor Extension is used, the error recovery interrupt level assigned to it will have a higher priority than a TASK executing on it, so that error handling is performed correctly.

EXECUTION STATUS

A TASK has an execution status or execution state. The OSP provides five execution states: RUNNING, READY, ASLEEP, SUSPENDED, and ASLEEP-SUSPENDED.

— A TASK is RUNNING if it has control of the processor.

— A TASK is READY if it is not asleep, suspended, or asleep-suspended. For a TASK to become the running (executing) TASK, it must be the highest priority TASK in the ready state.

— A TASK is ASLEEP if it is waiting for a request to be granted or a timer event to occur. A TASK may put itself into the ASLEEP state.

— A TASK is SUSPENDED if it is placed there by another TASK or if it suspends itself. A TASK may have multiple suspensions, the count of suspensions is managed by the OSP as the TASK suspension depth.

— A TASK is ASLEEP-SUSPENDED if it is both waiting and suspended.

TASK attributes, the CPU register values, and the 8087 register values (if the 8087 is configured into the application) are maintained by the OSP in the TASK state image. Each TASK will have a unique TASK state image.

SCHEDULING

The OSP schedules the processor time among the various TASKs on the basis of priority. A TASK has an execution priority relative to all other TASKs in the system, which the OSP maintains for each TASK in its TASK state image. When a TASK of higher priority than the executing TASK becomes ready to execute, the OSP switches the control of the processor to the higher priority TASK. First, the OSP saves the outgoing (lower priority) TASK's state including CPU register values in its TASK state image. Then, it restores the CPU registers from the TASK state image of the incoming (higher priority) TASK. Finally, it causes the CPU to start or resume executing the higher priority TASK.

TASK scheduling is performed by the OSP. The OSP's priority-oriented preemptive scheduler determines which TASK executes by comparing their relative priorities. The scheduler insures that the highest priority TASK with a status of READY will execute. A TASK will continue to execute until an interrupt with a higher priority occurs, or until it requests unavailable resources, for which it is willing to wait, or until it makes specific resources available to a higher priority TASK waiting for those resources.

TASKs can become READY by receiving a message, receiving control, receiving an interrupt, or by timing out. The OSP always monitors the status of all the TASKs (and interrupts) in the system. Preemptive scheduling allows the system to be responsive to the external environment while only devoting CPU resources to TASKs with work to be performed.

TIMED WAIT

The OSP timer hardware facilities support timed waits and timeouts. Thus, in many primitives, a TASK can specify the length of time it is prepared to wait for an event to occur, for the desired resources to become available or for a message to be received at a MAILBOX. The timing interval (or System Tick) can be adjusted, with a lower limit of 1 millisecond.

APPLICATION CONTROL OF TASK EXECUTION

Programs may alter TASK execution status and priority dynamically. One TASK may suspend its own execution or the execution of another TASK for a period of time, then resume its execution later. Multiple suspensions are provided. A suspended TASK may be suspended again.

The eight OSP Job and TASK management primitives are:

CREATE JOB	Partitions system resources and creates a TASK execution environment.
CREATE TASK	Creates a TASK state image. Specifies the location of the TASK code instruction stream, its execution priority, and the other TASK attributes.

DELETE TASK	Deletes the TASK state image, removes the instruction stream from execution and deallocates stack resources. Does not delete INTERRUPT TASKS.
SUSPEND TASK	Suspends the specified TASK or, if already suspended, increments its suspension depth by one. Execute state is SUSPEND.
RESUME TASK	Decrements the TASK suspension depth by one. If the suspension depth is then zero, the primitive changes the task execution status to READY, or ASLEEP (if ASLEEP/SUSPENDED).
SLEEP	Places the requesting TASK in the ASLEEP state for a specified number of System Ticks. (The TICK interval can be configured down to 1 millisecond.)
SET PRIORITY	Alters the priority of a TASK.

Interrupt Management

The OSP supports up to 256 interrupt levels organized in an interrupt vector, and up to 57 external interrupt sources of which one is the NMI (Non-Maskable Interrupt). The OSP manages each interrupt level independently. The OSF INTERRUPT SUBSYSTEM provides two mechanisms for interrupt management: INTERRUPT HANDLERs and INTERRUPT TASKs. INTERRUPT HANDLERs disable all maskable interrupts and should be used only for servicing interrupts that require little processing time. Within an INTERRUPT HANDLER only certain OSF Interrupt Management primitives (DISABLE, ENTER INTERRUPT, EXIT INTERRUPT, GET LEVEL, SIGNAL INTERRUPT) and basic CPU instructions can be used, other OSP primitives cannot be. The INTERRUPT TASK approach permits all OSP primitives to be issued and masks only lower priority interrupts.

Work flow between an INTERRUPT HANDLER and an INTERRUPT TASK assigned to the same level is regulated with the SIGNAL INTERRUPT and WAIT INTERRUPT primitives. The flow is asynchronous. When an INTERRUPT HANDLER signals an INTERRUPT TASK, the INTERRUPT HANDLER becomes immediately available to process another interrupt. The number of interrupts (specified for the level) the INTERRUPT HANDLER can queue for the INTERRUPT TASK can be limited to the value specified in the SET INTERRUPT primitive. When the INTERRUPT TASK is finished processing, it issues a WAIT INTERRUPT primitive, and is immediately ready to process the queue of interrupts that the INTERRUPT HANDLER has built with repeated SIGNAL INTERRUPT primitives while the INTERRUPT TASK was processing. If there were no interrupts at the level, the queue is empty and the INTERRUPT TASK is SUSPENDED. See the Example (Figure 5) and Figures 6 and 7.

OSP external INTERRUPT LEVELs are directly related to internal TASK scheduling priorities. The OSP maintains a single list of priorities including both tasks and INTERRUPT LEVELs. The priority of the executing TASK automatically determines which interrupts are masked. Interrupts are managed by INTERRUPT LEVEL number. The OSP supports eight levels directly and may be extended by means of slave 8259As to a total of 57.

The nine Interrupt Management OSP primitives are:

DISABLE	Disables an external INTERRUPT LEVEL.
ENABLE	Enables an external INTERRUPT LEVEL.
ENTER INTERRUPT	Gives an Interrupt Handler its own data segment, separate from the data segment of the interrupted task.
EXIT INTERRUPT	Performs an "END of INTERRUPT" operation. Used by an INTERRUPT HANDLER which does not invoke an INTERRUPT TASK. Reenables interrupts, when the INTERRUPT HANDLER gives up control.
GET LEVEL	Returns the interrupt level number of the executing INTERRUPT HANDLER.
RESET INTERRUPT	Cancels the previous assignment made to an interrupt level by SET INTERRUPT primitive request. If an INTERRUPT TASK has been assigned, it is also deleted. The interrupt level is disabled.
SET INTERRUPT	Assigns an INTERRUPT HANDLER to an interrupt level and, optionally, an INTERRUPT TASK.

```
/*  CODE EXAMPLE A   INTERRUPT TASK TO KEEP TRACK OF TIME-OF-DAY
DECLARE SECOND$COUNT BYTE,
    MINUTE$COUNT BYTE,
    HOURS$COUNT BYTE;
TIME$TASK:   PROCEDURE;
    DECLARE TIME$EXCEPT$CODE WORD;
    AC$CYCLE$COUNT=0;
    CALL RQ$SET$INTERRUPT(AC$INTERRUPT$LEVEL, 01H),
        @AC$HANDLER,0,@TIME$EXCEPT$CODE);
    CALL RQ$RESUME$TASK(INIT$TASK$TOKEN,@TIME$EXCEPT$CODE);
    DO HOUR$COUNT=0 TO 23;
        DO MINUTE$COUNT=0 TO 59;
            DO SECOND$COUNT=0 TO 59;
                CALL RQ$WAIT$INTERRUPT(AC$INTERRUPT$LEVEL,
                    @TIME$EXCEPT$CODE);
                IF SECOND$COUNT MOD 5=0
                    THEN CALL PROTECTED$CRT$OUT(BEL);
                END;    /*  SECOND LOOP  */
            END;    /*  MINUTE LOOP  */
        END;    /*  HOUR LOOP  */
    CALL RQ$RESET$INTERRUPT(AC$INTERRUPT$LEVEL, @TIME$EXCEPT$CODE);
    END TIME$TASK;
/*  CODE EXAMPLE B     INTERRUPT HANDLER TO SUBDIVIDE A.C. SIGNAL BY 60.  */
DECLARE AC$CYCLE$COUNT BYTE;
AC$HANDLER:   PROCEDURE INTERRUPT 59;
    DECLARE AC$EXCEPT$CODE WORD;
    AC$CYCLE$COUNT=AC$CYCLE$COUNT +1;
    IF AC$CYCLE$COUNT>=60 THEN DO;
        AC$CYCLE$COUNT=0;
        CALL RQ$SIGNAL$INTERRUPT(AC$INTERRUPT$LEVEL,@AC$EXCEPT$CODE);
        END;
    END   AC$HANDLER;
```

Figure 5. OSP Examples

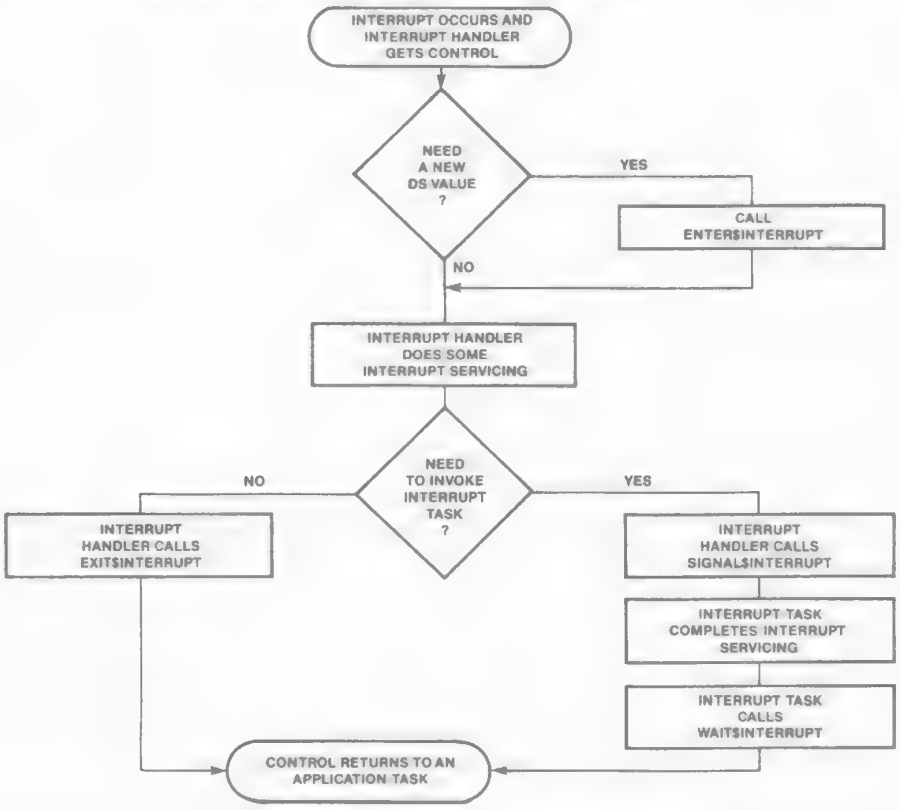


Figure 6. Interrupt Handling Flowchart

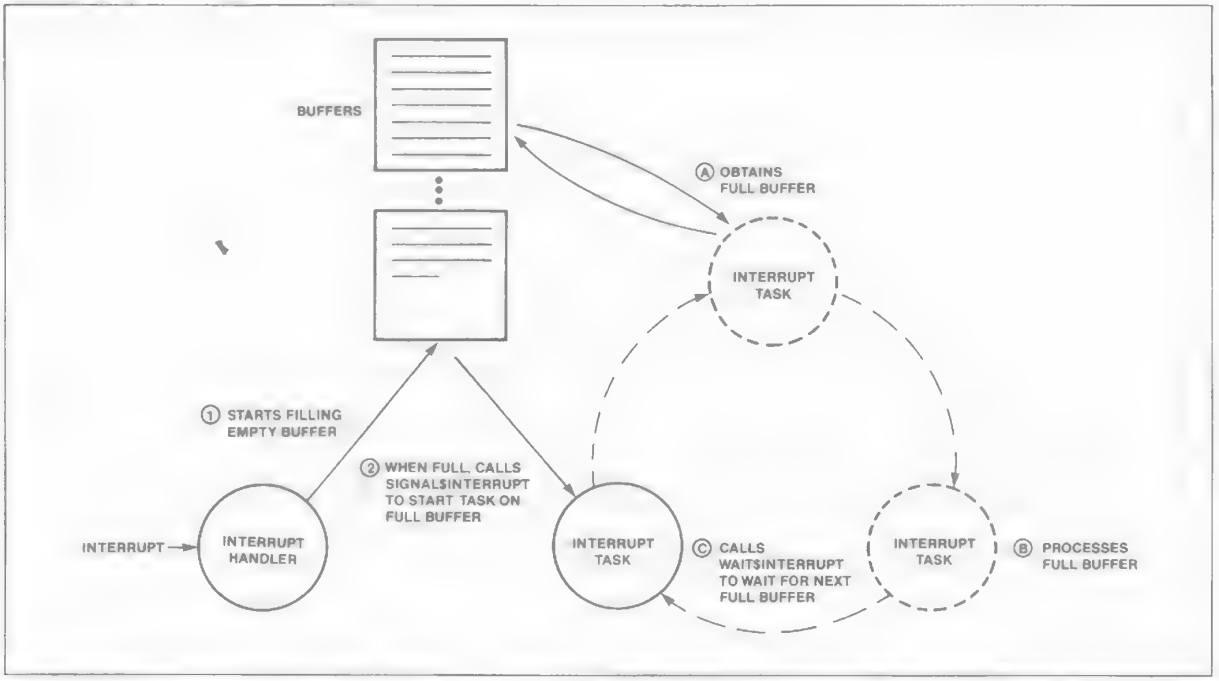


Figure 7. Multiple Buffer Example

SIGNAL INTERRUPT	Used by an INTERRUPT HANDLER to activate an Interrupt Task.
WAIT INTERRUPT	Suspends the calling Interrupt Task until the INTERRUPT HANDLER performs a SIGNAL INTERRUPT to invoke it. If a SIGNAL INTERRUPT for the task has occurred, it is processed.

FREE MEMORY MANAGEMENT

The OSP Free Memory Manager manages the memory pool which is allocated to each JOB for its execution needs. (The CREATE JOB primitive allocates the new JOB's memory pool from the memory pool of the parent JOB.) The memory pool is part of the JOB resources but is not yet allocated between the tasks of the JOB. When a TASK, MAILBOX, or REGION system data type structure is created within that JOB, the OSP implicitly allocates memory for it from the JOB's memory pool, so that a separate call to allocate memory is not required. OSP primitives that use free memory management implicitly include CREATE JOB, CREATE TASK, DELETE TASK, CREATE MAILBOX, DELETE MAILBOX, CREATE REGION, and DELETE REGION. The CREATE SEGMENT primitive explicitly allocates a memory area when one is needed by the TASK. For example, a TASK may explicitly allocate a SEGMENT for use as a memory buffer. The SEGMENT length can be any multiple of 16 bytes between 16 bytes and 64K bytes in length. The programmer may specify any number of bytes from 1 byte to 64 KB, the OSP will transparently round the value up to the appropriate segment size.

The two explicit memory allocation/deallocation primitives are:

CREATE SEGMENT	Allocates a SEGMENT of specified length (in 16-byte-long paragraphs) from the JOB Memory Pool.
DELETE SEGMENT	Deallocates the SEGMENT's memory area, and returns it to the JOB memory pool.

Intertask Communication

The OSP has built-in intertask synchronization and communication, permitting TASKs to pass and share information with each other. OSP MAILBOXes contain controlled handshaking facilities which guarantee that a *complete* message will always be sent from a sending TASK to a receiving TASK. Each MAILBOX consists of two interlocked queues, one of TASKs

and the other of Messages. Four OSP primitives for intertask synchronization and communication are provided:

CREATE MAILBOX	Creates intertask message exchange.
DELETE MAILBOX	Deletes an intertask message exchange.
RECEIVE MESSAGE	Calling TASK receives a message from the MAILBOX.
SEND MESSAGE	Calling TASK sends a message to the MAILBOX.

The CREATE MAILBOX primitive allocates a MAILBOX for use as an information exchange between TASKs. The OSP will post information at the MAILBOX in a FIFO (First-In First-Out) manner when a SEND MESSAGE instruction is issued. Similarily, a message is retrieved by the OSP if a TASK issues a RECEIVE MESSAGE primitive. The TASK which creates the MAILBOX may make it available to other TASKs to use.

If no message is available, the TASK attempting to receive a message may choose to wait for one or continue executing.

The queue management method for the task queue (FIFO or PRIORITY) determines which TASK in the MAILBOX TASK queue will receive a message from the MAILBOX. The method is specified in the CREATE MAILBOX primitive.

Intertask Synchronization and Mutual Exclusion

Mutual exclusion is essential to multiprogramming and multiprocessing systems. The REGION system data type implements mutual exclusion. A REGION is represented by a queue of TASKS waiting to use a resource which must be accessed by only one TASK at a time. The OSP provides primitives to use REGIONs to manage mutually exclusive data and resources. Both critical code sections and shared data structures can be protected by these primitives from simultaneous use by more than one task. REGIONs support both FIFO (First-In First-Out) or Priority queueing disciplines for the TASKS seeking to enter the REGION. The REGION SDT can also be used to implement software locks.

Multiple REGIONs are allowed, and are automatically exited in the reverse order of entry. While in a REGION, a TASK cannot be suspended by itself or any other TASK, and thereby avoids deadlock.

There are five OSP primitives for mutual exclusion:

CREATE REGION	Create a REGION (lock).
SEND CONTROL	Give up the REGION.
ACCEPT CONTROL	Request the REGION, but do not wait if it is not available.
RECEIVE CONTROL	Request a REGION, wait if not immediately available.
DELETE REGION	Delete a REGION.

The OSP also provides dynamic priority adjustment for TASKs within priority REGIONs: If a higher-priority TASK issues a RECEIVE CONTROL primitive, while a (lower-priority) TASK has the use of the same REGION, the lower-priority TASK will be transparently, and temporarily, elevated to the waiting TASK's priority until it relinquishes the REGION via SEND CONTROL. At that point, since it is no longer using the critical resource, the TASK will have its normal priority restored.

OSP Control Facilities

The OSP also includes system primitives that provide both control and customization capabilities to a multitasking system. These primitives are used to control the deletion of SDTs and the recovery of free memory in a system, to allow interrogation of operating system status, and to provide uniform means of adding user SDTs and type managers.

DELETION CONTROL

Deletion of each OSP system data type is explicitly controlled by the applications programmer by setting a deletion attribute for that structure. For example, if a SEGMENT is to be kept in memory until DMA activity is completed, its deletion attribute should be disabled. Each TASK, MAILBOX, REGION, and SEGMENT SDT is created with its deletion attribute enabled (i.e., they may be deleted). Two OSP primitives control the deletion attribute: ENABLE DELETION and DISABLE DELETION.

ENVIRONMENTAL CONTROL

The OSP provides inquiry and control operations which help the user interrogate the application environment and implement flexible exception handling. These features aid in run-time decision making and in application error processing and recovery. There are five OSP environmental control primitives.

DS EXTENSIONS

The OSP architecture is defined to allow new user-defined System Data Types and the primitives to manipulate them to be added to OSP capabilities

provided by the built-in System Data Types. The type managers created for the user-defined SDTs are called user OS extensions and are installed in the system by the SET OS EXTENSION primitive. Once installed, the functions of the type manager may be invoked with user primitives conforming to the OSP interface. For well-structured extended architectures, each OS extension should support a separate user-defined system data type, and every OS extension should provide the same calling sequence and program interface for the user as is provided for a built-in SDT. The type manager for the extension would be written to suit the needs of the application. OSP interrupt vector entries (224–255) are reserved for user OS extensions and are not used by the OSP. After assigning an interrupt number to the extension, the extension user may then call it with the standard OSP call sequence (Figure 4), and the unique software interrupt number assigned to the extension.

ENABLE DELETION	Allows a specific SEGMENT, TASK, MAILBOX, or REGION SDT to be deleted.
DISABLE DELETION	Prevents a specific SEGMENT, TASK, MAILBOX, or REGION SDT from being deleted.
GET TYPE	Given a token for an instance of a system data type, returns the type code.
GET TASK TOKENS	Returns to the caller information about the current task environment.
GET EXCEPTION HANDLER	Returns information about the calling TASK's current information handler: its address, and when it is used.
SET EXCEPTION HANDLER	Provides the address and usage of an exception handler for a TASK.
SET OS EXTENSION	Modifies one of the interrupt vector entries reserved for OS extensions (224–255) to point to a user OS extension procedure.
SIGNAL EXCEPTION	For use in OS extension error processing.

EXCEPTION HANDLING

The OSP supports exception handlers. These are similar to CPU exception handlers such as OVERFLOW and ILLEGAL OPERATION. Their purpose is to allow the OSP primitives to report parameter errors in primitive calls, and errors in primitive usage. Exception handling procedures are flexible and can be individually programmed by the application. In general, an exception handler if called will perform one or more of the following functions:

—Log the Error.
—Delete/Suspend the Task that caused the exception.
—Ignore the error, presumably because it is not serious.

An EXCEPTION HANDLER is written as a procedure. If PLM/86 is used, the "compact," "medium" or "large" model of computation should be specified for the compilation of the program. The mode in which the EXCEPTION HANDLER operates may be specified in the SET EXCEPTION HANDLER primitive. The return information from a primitive call is shown in Figure 4. CX is used to return standard system error conditions. Table 7 shows a list of these conditions, using the *default* EXCEPTION HANDLER of the OSP.

HARDWARE DESCRIPTION

The 80130 operates in a closely coupled mode with the iAPX 86/10 or 88/10 CPU. The 80130 resides on the CPU local multiplexed bus (Figure 8). The main processor is always configured for maximum mode operation. The 80130 automatically selects between its 88/30 and 86/30 operating modes.

The 80130 used in the 86/30 configuration, as shown in Figure 8 (or a similar 88/30 configuration), operates at both 5 and 8 MHz without requiring processor wait states. Wait state memories are fully supported, however. The 80130 may be configured with both an 8087 NPX and an 8089 IOP, and provides full context control over the 8087.

The 80130 (shown in Figure 3) is internally divided into a control unit (CU) and operating system unit (OSU). The OSU contains facilities for OSP kernel support including the system timers for scheduling and timing waits, and the interrupt controller for interrupt management support.

iAPX 86/30, iAPX 88/30 System Configuration

The 80130 is both I/O and memory mapped to the local CPU bus. The CPU's status S0/-S2/ is decoded along with IOCS/ (with BHE and AD_3–AD_0) or MEMCS/ (with AD_{13}–AD_0). The pins are internally latched. See Table 1 for the decoding of these lines.

Memory Mapping

Address lines A_{19}–A_{14} can be used to form MEMCS/ since the 80130's memory-mapped portion is aligned along a 16K-byte boundry. The 80130 can reside on any 16K-byte boundry excluding the highest (FC000H-FFFFFH) and lowest (00000H-003FFH). The 80130 control store code is position-independent except as limited above, in order to make it compatible with many decoding logic designs. AD_{13}–AD_0 are decoded by the 80130's kernel control store.

I/O Mapping

The I/O-mapped portion of the 80130 must be aligned along a 16-byte boundry. Address lines A_{15}–A_4 should be used to form IOCS/.

System Performance

The approximate performance of representitive OSP primitives is given in Table 5. These times are shown for a typical iAPX 86/30 implementation with an 8 MHz clock. These execution times are very comparable to the execution times of similar functions in minicomputers (where available) and are an order of magnitude faster than previous generation microprocessors.

Initialization

Both application system initialization and OSP-specific initialization/configuration are required to use the OSP. Configuration is based on a "database" provided by the user to the iOSP 86 support package. The OSP-specific initialization and configuration information area is assigned to a user memory address adjacent to the 80130's memory-mapped location. (See Application Note 130 for further details.) The configuration data defines whether 8087 support is configured in the system, specifies if slave 8259A interrupt controllers are used in addition to the 80130, and sets the operating system time base (Tick Interval). Also located in the configuration area are the exception handler control parameters, the address location of the (separate) application system configuration area and the OSP extensions in use. The OSP application system configuration area may be located anywhere in the user memory and must include the starting address of the application instruction code to be executed, plus the locations of the RAM memory blocks to be managed by the OSP free memory manager. Complete application system support and the required 80130 configuration support are provided by the iAPX 86/30 and iAPX 88/30 OPERATING SYSTEM PROCESSOR SUPPORT PACKAGE (iOSP 86).

RAM Requirements

The OSP manages its own interrupt vector, which is assigned to low RAM memory. Working RAM storage is required as stack space and data area. The memory space must be allocated in user RAM.

OSP interrupt vector memory locations 0H–3FFH must be RAM based. The OSP requires 2 bytes of allocated RAM. The processor working storage is dynamically allocated from free memory. Approximately 300 bytes of stack should be allocated for each OSP task.

TYPICAL SYSTEM CONFIGURATION

Figure 8 shows the processing cluster of a "typical" iAPX 86/30 or iAPX 88/30 OSP system. Not shown are subsystems likely to vary with the application. The configuration includes an 8086 (or 8088) operating in maximum mode, an 8284A clock generator and an 8288 system controller. Note that the 80130 is located on the CPU side of any latches or transceivers. See Intel Application Note 130 for further details on configuration.

OSP Timers

The OSP Timers are connected to the lower half of the data bus and are addressed at even addresses. The timers are read as two successive bytes, always LSB followed by MSB. The MSB is always latched on a read operation and remains latched until read. Timers are not gatable.

Baud Rate Generator

The baud rate generator is 8254 compatible (square wave mode 3). Its output, BAUD, is initially high and remains high until the Count Register is loaded. The first falling edge of the clock after the Count Register is loaded causes the transfer of the internal counter to the Count Register. The output stays high for N/2 [(N+1)/2 if N is odd] and then goes low for N/2 [(N−1)/2 if N is odd]. On the falling edge of the clock which signifies the final count for the output in low state, the output returns to high state and the Count Register is transferred to the internal counter. The whole process is then repeated. Baud Rates are shown in Table 6.

The baud rate generator is located at 0CH (12), relative to the 16-byte boundary in the I/O space in which the 80130 component is located ("OSF" in the following example), the timer control word is located at

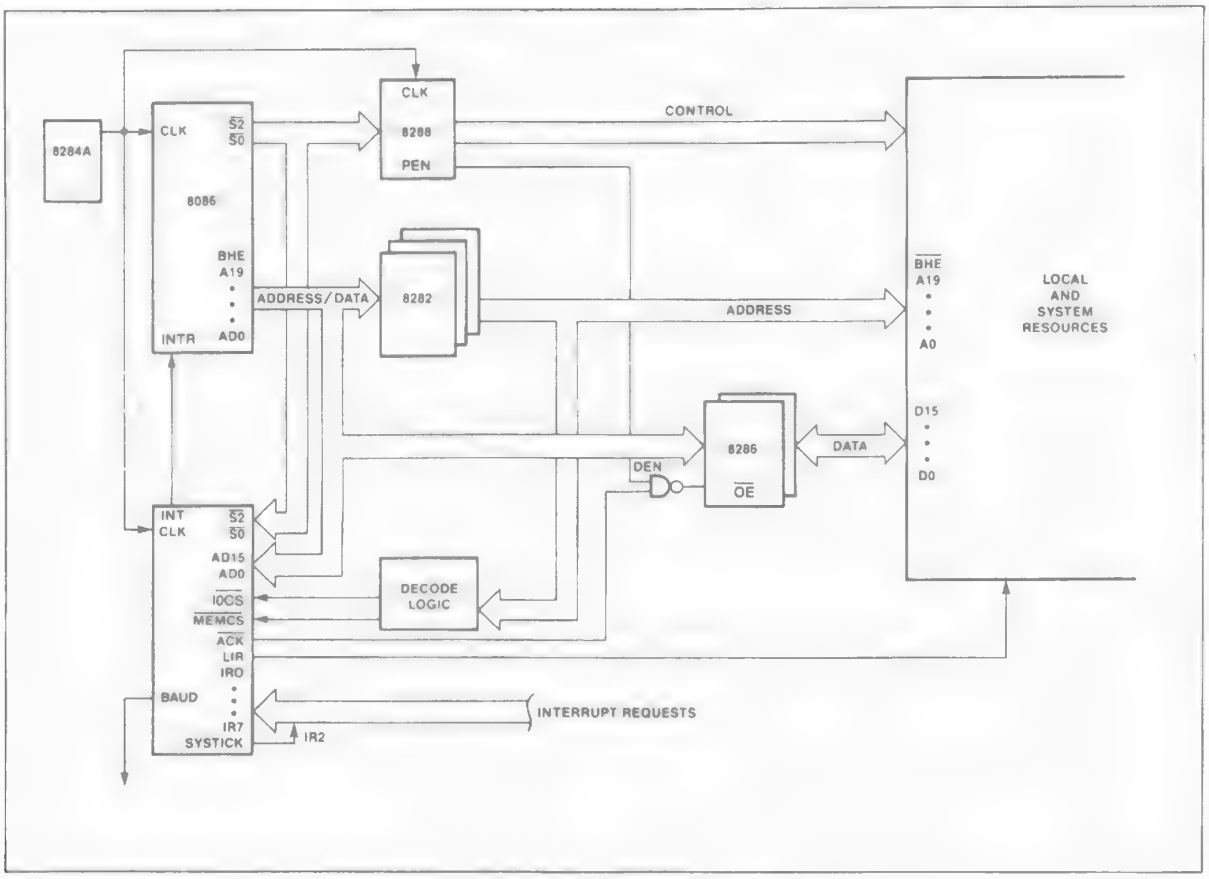


Figure 8. Typical OSP Configuration

relative address, 0EH(14). Timers are addressed with IOCS=0. Timers 0 and 1 are assigned to the use by the OSP, and should not be altered by the user.

For most baud-rate generator applications, the command byte

0B6H Read/Write Baud-Rate Delay Value

will be used. A typical sequence to set a baud rate of 9600 using a count value of 52 follows (see Table 6):

```
MOV   AX,0B6H      ;Prepare to Write Delay to
                    Timer 3.
OUT   OSF+14,AX    ;Control Word.
MOV   AX, 52
OUT   OSF+12,AL    ;LSB written first
XCHG  AL,AH
OUT   OSF+12,AL    ;MSB written after.
```

The 80130 timers are subset compatible with 8254 timers.

Interrupt Controller

The Programmable Interrupt Controller (PIC), is also an integral unit of the 80130. Its eight input pins handle eight vectored priority interrupts. One of these pins must be used for the SYSTICK time function in timing waits, using an external connection as shown. During the 80130 initialization and configuration sequence, each 80130 interrupt pin is individually programmed as either level or edge sensitive. External slave 8259A interrupt controllers can be used to expand the total number of OSP external interrupts to 57.

In addition to standard PIC funtions, 80130 PIC unit has an $\overline{LIR}$ output signal, which when low indicates an interrupt acknowledge cycle. $\overline{LIR}$=0 is provided to control the 8289 Bus Arbiter SYSB/$\overline{RESB}$ pin. This will avoid the need of requesting the system bus to acknowledge local bus non-slave interrupts. The user defines the interrupt system as part of the configuration.

INTERRUPT SEQUENCE

The OSP interrupt sequence is as follows:

1. One or more of the interrupts is set by a low-to-high transition on edge-sensitive IR inputs or by a high input on level-sensitive IR inputs.
2. The 80130 evaluates these requests, and sends an INT to the CPU, if appropriate.
3. The CPU acknowledges the INT and responds with an interrupt acknowledge cycle which is encoded in $\overline{S_2}$-$\overline{S_0}$.
4. Upon receiving the first interrupt acknowledge from the CPU, the highest-priority interrupt is set by the 80130 and the corresponding edge detect latch is reset. The 80130 does not drive the address/data bus during this bus cycle but does acknowledge the cycle by making $\overline{ACK}$=0 and sending the $\overline{LIR}$ value for the IR input being acknowledged.
5. The CPU will then initiate a second interrupt acknowledge cycle. During this cycle, the 80130 will supply the cascade address of the interrupting input at T_1 on the bus and also release an 8-bit pointer onto the bus if appropriate, where it is read by the CPU. If the 80130 does supply the pointer, then $\overline{ACK}$ will be low for the cycle. This cycle also has the value $\overline{LIR}$ for the IR input being acknowledged.
6. This completes the interrupt cycle. The ISR bit remains set until an appropriate EXIT INTERRUPT primitive (EOI command) is called at the end of the Interrupt Handler.

OSP APPLICATION EXAMPLE

Figure 5 shows an application of the OSP primitives to keep track of time of day in a simplified example. The system design uses a 60 Hz A.C. signal as a time base. The power supply provides a TTL-compatible signal which drives one of 80130 edge-triggered interrupt request pins once each A.C. cycle. The Interrupt Handler responds to the interrupts, keeping track of one second's A.C. cycles. The Interrupt Task counts the seconds and after a day deletes itself. In typical systems it might perform a data logging operation once each day. The Interrupt Handler and Interrupt Task are written as separate modular programs.

The Interrupt Handler will actually service interrupt 59 when it occurs. It simply counts each interrupt, and at a count of 60 performs a SIGNAL INTERRUPT to notify the Interrupt Task that a second has elapsed. The Interrupt Handler (ACS HANDLER) was assigned to this level by the SET INTERRUPT primitive. After doing this, the Interrupt Task performed the Primitive RESUME TASK to resume the application task (INITS TASKS TOKEN).

The main body of the task is the counting loop. The Interrupt Task is signaled by the SIGNAL INTERRUPT primitive in the Interrupt Handler (at interrupt level ACS INTERRUPTS LEVEL). When the task is signalled by the Interrupt Handler it will execute the loop exactly one time, increasing the time count variables. Then it will execute the WAIT INTERRUPT primitive, and wait until awakened by the Interrupt Handler. Normally, the task will now wait some period of time for the next signal. However, since the interface between the Handler and the Task is asynchronous, the handler may have already queued the interrupt for servicing, the writer of the task does not have to worry about this possibility.

At the end of the day, the task will exit the loop and execute RESET INTERRUPT, which disables the interrupt level, and deletes the interrupt task. The OSP now reclaims the memory used by the Task and schedules another task. If an exception occurs, the coded value for the exception is available in TIMES EXCEPTS CODE after the execution of the primitive.

A typical PL/M-86 calling sequence is illustrated by the call to RESET INTERRUPT shown in Figure 5.

Table 2. OSP System Data Type Summary

Job	Jobs are the means of organizing the program environment and resources. An application consists of one or more jobs. Each iAPX 86/30 system data type is contained in some job. Jobs are independent of each other, but they may share access to resources. Each job has one or more tasks, one of which is an initial task. Jobs are given pools of memory, and they may create subordinate offspring jobs, which may borrow memory from their parents.
Task	Tasks are the means by which computations are accomplished. A task is an instruction stream with its own execution stack and private data. Each task is part of a job and is restricted to the resources provided by its job. Tasks may perform general interrupt handling as well as other computational functions. Each task has a set of attributes, which is maintained for it by the iAPX 86/30, which characterize its status. These attributes are: its containing job its register context its priority (0–255) its execution state (asleep, suspended, ready, running, asleep/suspended). its suspension depth its user-selected exception handler its optional 8087 extended task state
Segment	Segments are the units of memory allocation. A segment is a physically contiguous sequence of 16-byte, 8086 paragraph-length, units. Segments are created dynamically from the free memory space of a Job as one of its Tasks requests memory for its use. A segment is deleted when it is no longer needed. The iAPX 86/30 maintains and manages free memory in an orderly fashion, it obtains memory space from the pool assigned to the containing job of the requesting task and returns the space to the job memory pool (or the parent job pool) when it is no longer needed. It does not allocate memory to create a segment if sufficient free memory is not available to it, in that case it returns an error exception code.
Mailbox	Mailboxes are the means of intertask communication. Mailboxes are used by tasks to send and receive message segments. The iAPX 86/30 creates and manages two queues for each mailbox. One of these queues contains message segments sent to the mailbox but not yet received by any task. The other mailbox queue consists of tasks that are waiting to receive messages. The iAPX 86/30 operation assures that waiting tasks receive messages as soon as messages are available. Thus at any moment one or possibly both of two mailbox queues will be empty.
Region	Regions are the means of serialization and mutual exclusion. Regions are familiar as "critical code regions." The iAPX 86/30 region data type consists of a queue of tasks. Each task waits to execute in mutually exclusive code or to access a shared data region, for example to update a file record.
Tokens	The OSP interface makes use of a 16-bit TOKEN data type to identify individual OSF data structures. Each of these (each instance) has its own unique TOKEN. When a primitive is called, it is passed the TOKENs of the data structures on which it will operate.

Table 3. System Data Type Codes and Attributes

S.D.T.	Code	Attributes
Jobs	1	Tasks Memory Pool S.D.T. Directory
Tasks	2	Priority Stack Code State Exception Handler
Mailboxes	3	Queue of S.D.T.s (generally segments) Queue of Tasks waiting for S.D.T.s
Region	5	Queue of Tasks waiting for mutually exclusive code or data
Segments	6	Buffer Length

Table 4. OSP Primitives

Class	OSP Primitive	Interrupt Number	Entry Code in AX	Parameters On Caller's Stack
JOB	CREATE JOB	184	0100H	*See 80130 User Manual
TASK	CREATE TASK	184	0200H	Priority, IP Ptr, Data Segment, Stack Seg, Stack Size Task Information, ExcptPtr
	DELETE TASK	184	0201H	TASK, ExcptPtr
	SUSPEND TASK	184	0202H	TASK, ExcptPtr
	RESUME TASK	184	0203H	TASK, ExcptPtr
	SET PRIORITY	184	0209H	TASK, Priority, ExcptPtr
	SLEEP	184	0204H	Time Limit,ExcptPtr
INTERRUPT	DISABLE	190	0705H	Level, ExcptPtr
	ENABLE	184	0704H	Level #, ExcptPtr
	ENTER INTERRUPT	184	0703H	Level #, ExcptPtr
	EXIT INTERRUPT	186	NONE	Level #,ExcptPtr
	GET LEVEL	188	0702H	Level #, ExcptPtr
	RESET INTERRUPT	184	0706H	Level #, ExcptPtr
	SET INTERRUPT	184	0701H	Level, Interrupt Task Flag Interrupt Handler Ptr, Interrupt Handler DataSeg ExcptPtr
	SIGNAL INTERRUPT	185	NONE	Level, ExcptPtr
	WAIT INTERRUPT	187	NONE	Level, ExcptPtr
SEGMENT	CREATE SEGMENT	184	0600H	Size, ExcptPtr
	DELETE SEGMENT	184	0603H	SEGMENT, ExceptPtr

Table 4. OSP Primitives (Continued)

Class	OSP Primitive	Interrupt Number	Entry Code in AX	Parameters On Caller's Stack
MAILBOX	CREATE MAILBOX	184	0300H	Mailbox flags, ExcptPtr
	DELETE MAILBOX	184	0301H	MAILBOX, ExcptPtr
	RECEIVE MESSAGE	184	0303H	MAILBOX, Time Limit ResponsePtr, ExcptPtr
	SEND MESSAGE	184	0302H	MAILBOX,Message Response, ExcptPtr
REGION	ACCEPT CONTROL	184	0504H	REGION, ExcptPtr
	CREATE REGION	184	0500H	Region Flags, ExcptPtr
	DELETE REGION	184	0501H	REGION, ExcptPtr
	RECEIVE CONTROL	184	0503H	REGION, ExcptPtr
	SEND CONTROL	184	0502H	ExcptPtr
ENVIRONMENTAL	DISABLE DELETION	184	0001H	TOKEN,ExcptPtr
	ENABLE DELETION	184	0002H	TOKEN,ExcptPtr
	GET EXCEPTION HANDLER	184	0800H	Ptr,ExcptPtr
	GET TYPE	184	0000H	TOKEN,ExcptPtr
	GET TASK TOKENS	184	0206H	Request, ExcptPtr
	SET EXCEPTION HANDLER	184	0801H	Ptr, ExcptPtr
	SET OS EXTENSION	184	0700H	Code,InstPtr, ExcptPtr
	SIGNAL EXCEPTION	184	0802H	Exception Code, Parameter Number, StackPtr,0,0,ExcptPtr

NOTES:
All parameters are pushed onto the OSP stack. Each parameter is one word. See Figure 3 for Call Sequence.

Explanation of the Symbols

JOB	OSP JOB SDT Token
TASK	OSP TASK SDT Token
REGION	OSP REGION SDT Token
MAILBOX	OSP MAILBOX SDT Token
SEGMENT	OSP SEGMENT SDT Token
TOKEN	Any SDT Token
Level	Interrupt Level Number
ExcptPtr	Pointer to Exception Code
Message	Message Token
Ptr	Pointer to Code,Stack etc. Address
Seg	Value Loaded into appropriate Segment Register
----	Value Parameter.

Table 5. OSP Primitive Performance Examples

Datatype Class	Primitive Execution Speed* (microseconds)	
JOB	CREATE JOB	2950
TASK	CREATE TASK (no preemption)	1360
SEGMENT	CREATE SEGMENT	700
MAILBOX	SEND MESSAGE (with task switch)	475
	SEND MESSAGE (no task switch)	265
	RECEIVE MESSAGE (task waiting)	540
	RECEIVE MESSAGE (message waiting)	260
REGION	SEND CONTROL	170
	RECEIVE CONTROL	205

*8 MHz iAPX 86/30 OSP Configuation.

Table 6. Baud Rate Count Values (16X)

Baud Rate	8 MHz Count Value	5 MHz Count Value
300	1667	1042
600	833	521
1200	417	260
2400	208	130
4800	104	65
9600	52	33

Table 7a. Mnemonic Codes for Unavoidable Exceptions

E$OK	Exception Code Value = 0 the operation was successful
E$TIME	Exception Code Value = 1 the specified time limit expired before completion of the operations was possible
E$MEM	Exception Code Value = 2 insufficient nucleus memory is available to satisfy the request
E$BUSY	Exception Code Value = 3 specified region is currently busy
E$LIMIT	Exception Code Value = 4 attempted violation of a job, semaphore, or system limit
E$CONTEXT	Exception Code Value = 5 the primitive was called in an illegal context (e.g., call to enable for an already enabled interrupt)
E$EXIST	Exception Code Value = 6 a token argument does not currently refer to any object; note that the object could have been deleted at any time by its owner
E$STATE	Exception Code Value = 7 attempted illegal state transition by a task
ENOTCONFIGURED	Exception Code Value = 8 the primitive called is not configured in this system
E$INTERRUPT$SATURATION	Exception Code Value = 9 The interrupt task on the requested level has reached its user specified saturation point for interrupt service requests. No further interrupts will be allowed on the level until the interrupt task executes a WAIT$INTERRUPT. (This error is only returned, in line, to interrupt handlers.)
E$INTERRUPT$OVERFLOW	Exception Code Value = 10 The interrupt task on the requested level previously reached its saturation point and caused an E$INTERRUPT$SATURATION condition. It subsequently executed an ENABLE allowing further interrupts to come in and has received another SIGNAL$INTERRUPTcall, bringing it over its specified saturation point for interrupt service requests. (This error is only returned, in line, to interrupt handlers).

Table 7b. Mnemonic Codes for Avoidable Exceptions

E$ZERO$DIVIDE	Exception Code Value = 8000H divide by zero interrupt occurred
E$OVERFLOW	Exception Code Value = 8001H overflow interrupt occurred
E$TYPE	Exception Code Value = 8002H a token argument referred to an object tha was not of required type
E$BOUNDS	Exception Code Value = 8003H an offset argument is out of segment bounds
E$PARAM	Exception Code Value = 8004H a (non-token,non-offset) argument has an illegal value
EBADCALL	Exception Code Value = 8005H an entry code for which there is no corresponding primitive was passed
E$ARRAY$BOUNDS = 8006H	Hardware or Language has detected an array overflow
ENDPERROR	Exception Code Value = 8007H an 8087 (Numeric data Processor) error has been detected; (the 8087 status information is contained in a parameter to the exception handler)

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to 150°C
Voltage on Any Pin With
Respect to Ground ..... −1.0V to +7V
Power Dissipation ..... 1.0 Watts

**NOTICE: Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended period may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 4.5 to 5.5V)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + .5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400 μA
I_{CC}	Power Supply Current		300	mA	T_A = 25 C
I_{LI}	Input Leakage Current		10	μA	$0 < V_{IN} < V_{CC}$
I_{LR}	IR Input Load Current		10 −300	μA μA	$V_{IN} = V_{CC}$ $V_{IN} = 0$
I_{LO}	Output Leakage Current		10	μA	$.45 \leq V_{IN} \leq V_{CC}$
V_{CLI}	Clock Input Low		0.6	V	
V_{CHI}	Clock Input High	3.9		V	
C_{IN}	Input Capacitance		10	pF	
C_{IO}	I/O Capacitance		15	pF	

A.C. CHARACTERISTICS (T_A = 0–70°C, V_{CC} = 4.5–5.5 Volt, V_{SS} = Ground)

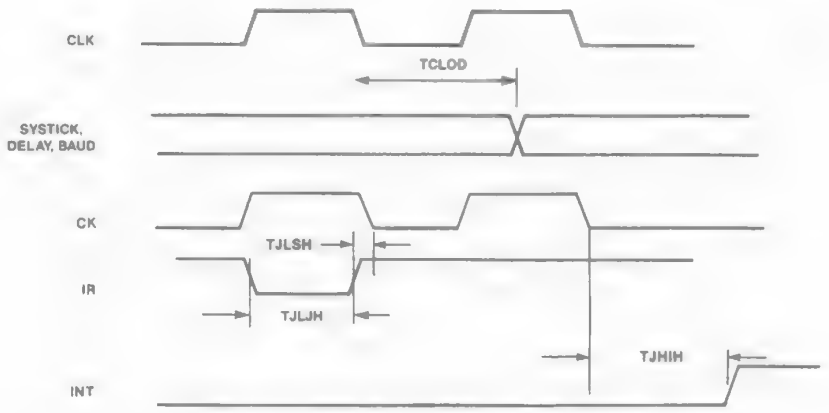
Symbol	Parameter	Min.	Max.	Units	Notes
T_{CLCL}	CLK Cycle Period	125	—	ns	C_L = 20–200 pF
T_{CLCH}	CLK Low Time	55	—	ns	
T_{CHCL}	CLK High Time	44	2000	ns	
T_{SVCH}	Status Active Setup Time	55	—	ns	
T_{CHSV}	Status Inactive Hold Time	10	—	ns	
T_{SHCL}	Status Inactive Setup Time	55	—	ns	
T_{CLSH}	Status Active Hold Time	10	—	ns	
T_{ASCH}	Address Valid Setup Time	5	—	ns	
T_{CLAH}	Address Hold Time	10	—	ns	
T_{CSCL}	Chip Select Setup Time	20	—	ns	
T_{CHCS}	Chip Select Hold Time	0	—	ns	
T_{DSCL}	Write Data Setup Time	60	—	ns	
T_{CHDH}	Write Data Hold Time	10	—	ns	
T_{JLJH}	IR Low Time	100	—	ns	
T_{ACC}	Read Data from Address		290	ns	
T_{CLDV}	Read Data Valid Delay	—	100	ns	
T_{CLDH}	Read Data Hold Time	10	—	ns	
T_{CLDX}	Read Data to Floating	TCLDH	100	ns	
T_{CLCA}	Cascade Address Delay Time	—	55	ns	
T_{IACA}	INTA Status to Cascade	—	55	ns	

A.C. CHARACTERISTICS (Continued)

Symbol	Parameter	Min.	Max.	Units	Notes
T_{CLCF}	Cascade Address Hold Time	10	—	ns	
T_{IAVE}	INTA Status to Acknowledge	—	80	ns	
T_{CHEH}	Acknowledge Hold Time	10	—	ns	
T_{CSAK}	Chip Select to ACK	—	110	ns	
T_{SACK}	Status to ACK	—	140	ns	
T_{AACK}	Address to ACK	—	90	ns	
T_{CLOD}	Timer Output Delay Time	—	200	ns	C_L = 100 pF
T_{CLOD1}	Timer1 Output Delay Time	—	$200+T_{CLCL}$	ns	C_L = 100 pF
T_{JHIH}	INT Output Delay	—	200	ns	
T_{JLSH}	IR Setup Time	10	—	ns	

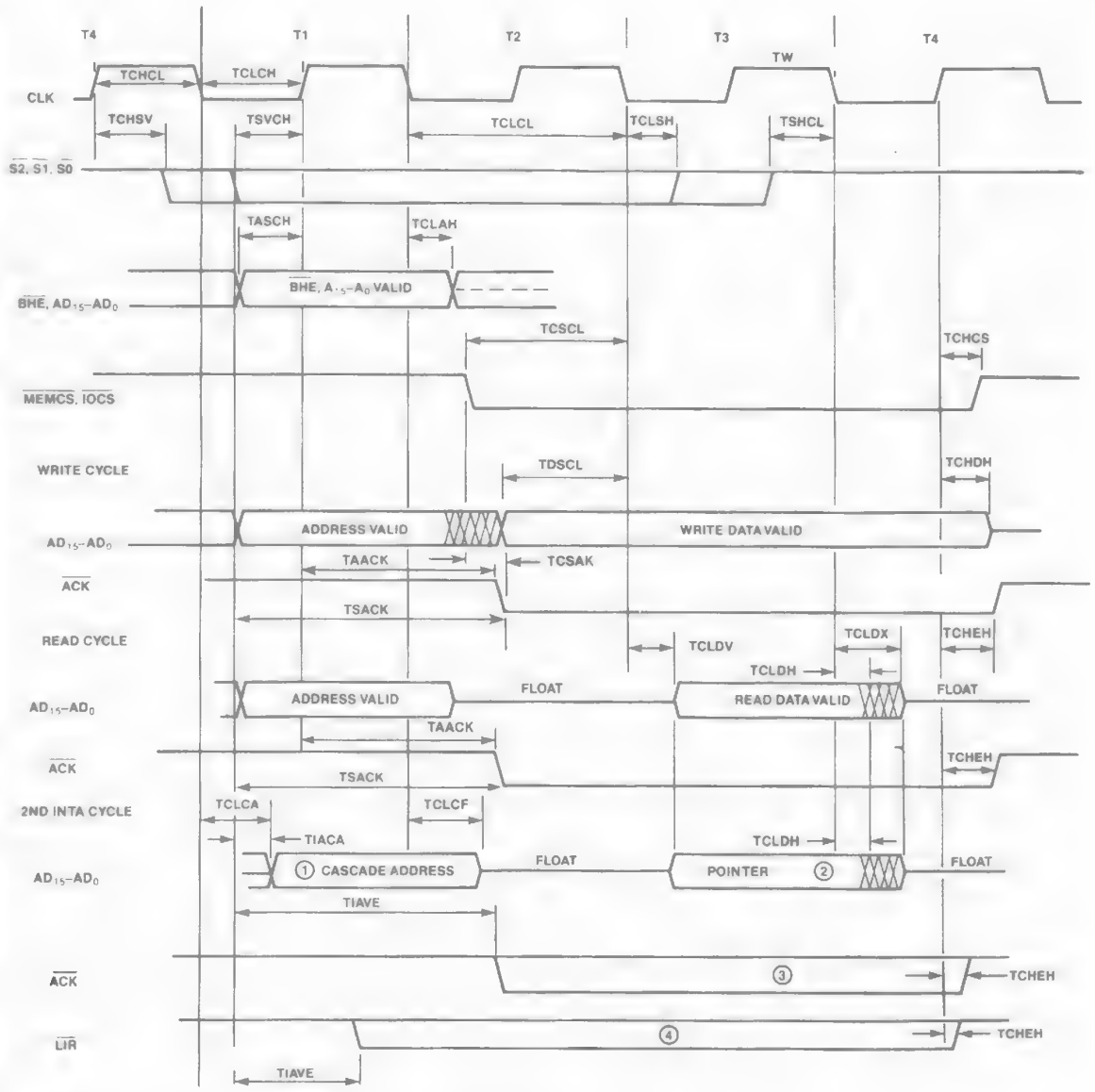
WAVEFORMS

A.C.



WAVEFORMS

D.C.



NOTES:
1. CASCADE ADDRESS PRESENTED ON AD8, AD9 and AD10 CORRESPONDING TO CAS0, CAS1 and CAS2 RESPECTIVELY. AD11, AD12, AD13, AD14 AND AD15 ARE ACTIVE AND HAVE UNKNOWN VALUES. THE LOWER BYTE ADI IS TRISTATED.
2. POINTER VALUE IS ACTIVE ONLY IF POINTER IS GENERATED FROM THE 80130 AND NOT FROM EXTERNAL SLAVE UNIT.
3. ACTIVE LOW ONLY WHEN POINTER DATA IS BEING SUPPLIED BY THE 80130.
4. LOW ONLY FOR LOCAL INTERRUPT.

ADVANCE INFORMATION

iAPX 86/50, 88/50, 186/50, 188/50 CP/M-86* OPERATING SYSTEM PROCESSORS

(80150-2)

- **High-Performance Two-Chip Data Processors Containing the Complete CP/M-86 Operating System**
- **Standard On-Chip BIOS (Basic Input/Output System) Contains Drivers for 8272A, 8275, 8274, 8255A, 8251A, 8237A**
- **BIOS Extensible with User-Supplied Peripheral Drivers**
- **User Intervention Points Allow Addition of New System Commands**
- **Memory Disk Makes Possible Diskless CP/M-86 Systems**
- **No License or Serialization Required**
- **Built-in Operating System Timers and Interrupt Controller**
- **8086/8087/8088/80186/80188 Compatible at Up to 8 MHz Without Wait States**

The Intel iAPX 86/50, 88/50, 186/50, and 188/50 are two-chip microprocessors offering general-purpose CPU instructions combined with the CP/M-86 operating system. Respectively, they consist of the 8- and 16-bit software compatible 8086, 8088, 80186, and 80188 CPU plus the 80150 CP/M-86 operating system extension.

CP/M-86 is a single-user operating system designed for computers based on the Intel iAPX 86, 88, 186, and 188 microprocessors. The system allows full utilization of the one megabyte of memory available for application programs. The 80150 stores CP/M-86 in its 16K bytes of on-chip memory. The 80150 will run third-party applications software written to run under standard Digital Research CP/M-86.

The 80150 is implemented in N-Channel, depletion-load, silicon-gate technology (HMOS), and is housed in a 40-pin package. Included on the 80150 are the CP/M-86 operating system, Version 1.1, plus hardware support for eight interrupts, a system timer, a delay timer, and a baud rate generator.

*CP/M-86 is a trademark of Digital Research, Inc.

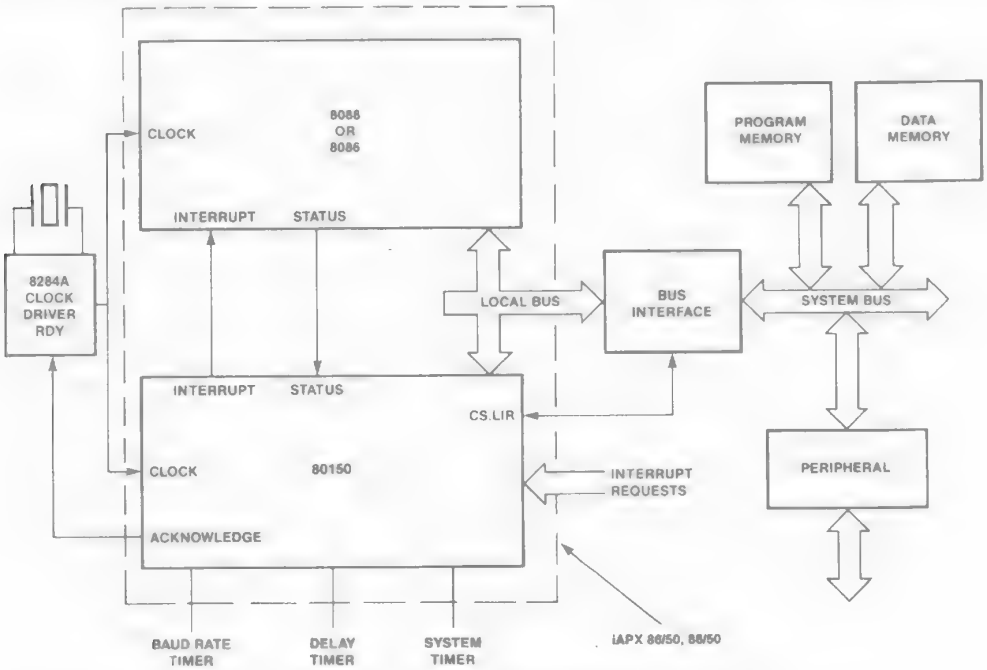


Figure 1. iAPX 86/50, 88/50 Block Diagram

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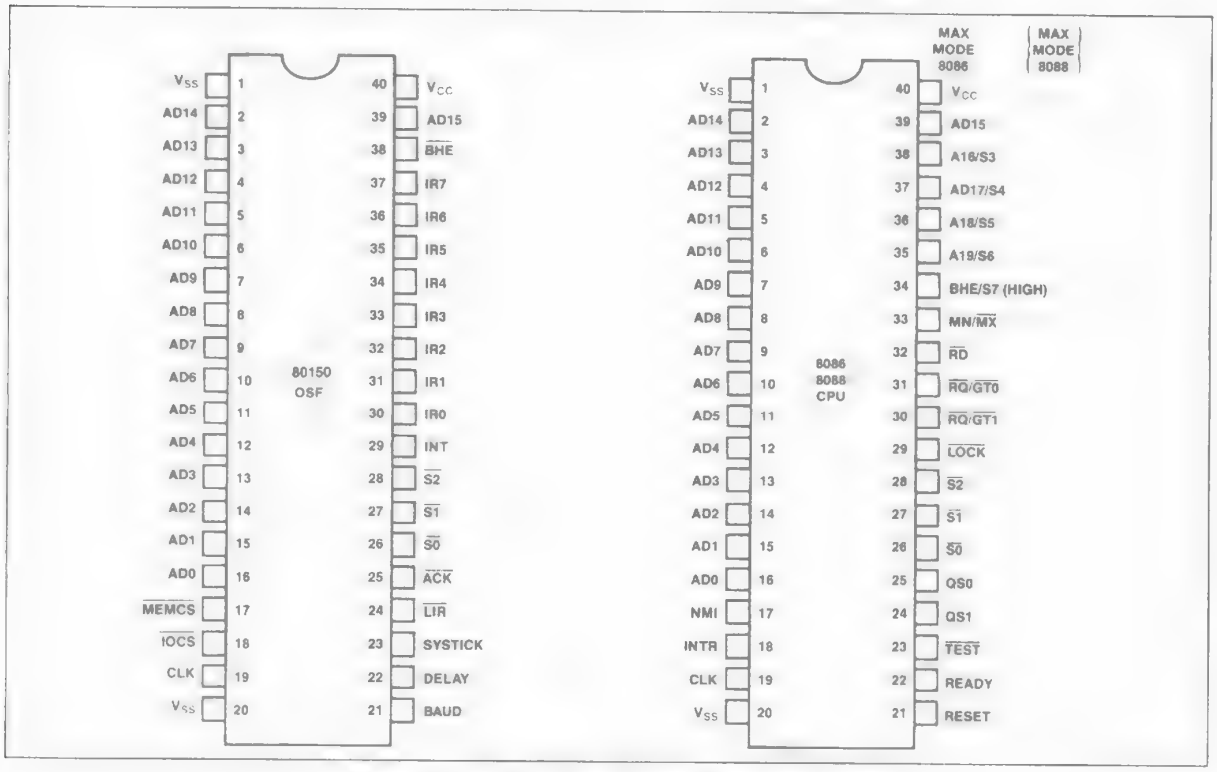

Figure 2. iAPX 86/50, 88/50 Pin Configuration

Table 1. 80150 Pin Description

Symbol	Type	Name and Function
AD_{15}–AD_0	I/O	**Address Data:** These pins constitute the time multiplexed memory address (T_1) and data (T_2, T_3, T_W, T_4) bus. These lines are active HIGH. The address presented during T_1 of a bus cycle will be latched internally and interpreted as an 80150 internal address if MEMCS or IOCS is active for the invoked primitives. The 80150 pins float whenever it is not chip selected, and drive these pins only during $T_2 - T_4$ of a read cycle and T_1 of an INTA cycle.
$\overline{BHE}/S_7$	I	**Bus High Enable:** The 80150 uses the BHE signal from the processor to determine whether to respond with data on the upper or lower data pins, or both. The signal is active LOW. BHE is latched by the 80150 on the trailing edge of ALE. It controls the 80150 output data as shown. $\overline{BHE}$ A_0 0 0 Word on AD_{15}–AD_0 0 1 Upper byte on $AD_{15} - AD_8$ 1 0 Lower byte on AD_7–AD_0 1 1 Upper byte on AD_7–AD_0
$\overline{S_2}$, $\overline{S_1}$, $\overline{S_0}$	I	**Status:** For the 80150, the status pins are used as inputs only. 80150 encoding follows: $\overline{S_2}$ $\overline{S_1}$ $\overline{S_0}$ 0 0 0 INTA 0 0 1 IORD 0 1 0 IOWR 0 1 1 Passive 1 0 0 Instruction fetch 1 0 1 MEMRD 1 1 X Passive

Table 1. 80150 Pin Description (Continued)

Symbol	Type	Name and Function
CLK	I	**Clock:** The system clock provides the basic timing for the processor and bus controller. It is asymmetric with a 33% duty cycle to provide optimized internal timing. The 80130 uses the system clock as an input to the SYSTICK and BAUD timers and to synchronize operation with the host CPU.
INT	O	**Interrupt:** INT is HIGH whenever a valid interrupt request is asserted. It is normally used to interrupt the CPU by connecting it to INTR.
IR_7–IR_0	I	**Interrupt Requests:** An interrupt request can be generated by raising an IR input (LOW to HIGH) and holding it HIGH until it is acknowledged (Edge-Triggered Mode), or just by a HIGH level on an IR input (Level-Triggered Mode).
$\overline{ACK}$	O	**Acknowledge:** This line is LOW whenever an 80150 resource is being accessed. It is also LOW during the first INTA cycle and second INTA cycle if the 80150 is supplying the interrupt vector information. This signal can be used as a bus ready acknowledgement and/or bus transceiver control.
$\overline{MEMCS}$	I	**Memory Chip Select:** This input must be driven LOW when a kernel primitive is being fetched by the CPU. AD_{13}–AD_0 are used to select the instruction.
$\overline{IOCS}$	I	**Input/Output Chip Select:** When this input is low, during an IORD or IOWR cycle, the 80150's kernel primitives are accessing the appropriate peripheral function as specified by the following table: $\overline{BHE}$ A_3 A_2 A_1 A_0 0 X X X X Passive X X X X 1 Passive X 0 1 X X Passive 1 0 0 X 0 Interrupt Controller 1 1 0 0 0 Systick Timer 1 1 0 1 0 Delay Counter 1 1 1 0 0 Baud Rate Timer 1 1 1 1 0 Timer Control
$\overline{LIR}$	O	**Local Bus Interrupt Request:** This signal is LOW when the interrupt request is for a non-slave input or slave input programmed as being a local slave.
V_{CC}		**Power:** V_{CC} is the +5V supply pin.
V_{SS}		**Ground:** V_{SS} is the ground pin.
SYSTICK	O	**System Clock Tick:** Timer 0 Output. Operating System Clock Reference. SYSTICK is normally wired to IR2 to implement operating system timing interrupt.
DELAY	O	**DELAY Timer:** Output of timer 1. Reserved by Intel Corporation for future use.
BAUD	O	**Baud Rate Generator:** 8254 Mode 3 compatible output. Output of 80150 Timer 2.

The 80150 breaks new ground in operating system software-on-silicon components. It is unique because it is the first time that an industry-standard personal/small business computer operating system is being put in silicon. The 80150 contains Digital Research's CP/M-86 operating system, which is designed for Intel's line of software- and interface-compatible iAPX 86, 88, 186, and 188 microprocessors. Since the entire CP/M-86 operating system is contained on the chip, it is now possible to design a diskless computer that runs proven and commonly available applications software. The 80150 is a true operating system extension to the host microprocessor, since it also integrates key operating system-related peripheral functions onto the chip.

MODULAR DESIGN

Based on a proven, modular design, the system includes the:

- CCP: Console Command Processor

  The CCP is the human interface to the operating system and performs decoding and

execution of user commands.

- BDOS: Basic Disk Operating System

  The BDOS is the logical, invariant portion of the operating system; it supports a named file system with a maximum of 16 logical drives, containing up to 8 megabytes each for a potential of 128 megabytes of on-line storage.

- BIOS: Basic Input/Output System

  The physical, variant portion of the operating system, the BIOS contains the system-dependent input/output device handlers.

CP/M* COMPATIBILITY

CP/M-86 files are completely compatible with CP/M for 8080- and 8085-based microcomputer systems. This simplifies the conversion of software developed under CP/M to take full advantage of iAPX 86, 88, 186, 188-based systems.

The user will notice no significant difference between CP/M and CP/M-86. Commands such as DIR, TYPE, REN, and ERA respond the same way in both systems.

CP/M-86 uses the iAPX 86, 88, 186, 188 registers corresponding to 8080 registers for system call and return parameters to further simplify software transport. The 80150 allows application code and data segments to overlap, making the mixture of code and data that often appears in CP/M applications acceptable to the iAPX 86, 88, 186, 188.

Unique Capabilities of CP/M-86 in Silicon

1. CP/M-86 on-a-chip reduces software development required by the system designer. It can change the implementation of the operating system into the simple inclusion of the 80150 on the CPU board.

   As described later, the designer can either simply incorporate the Intel chip without the need for writing even a single line of additional code, or he can add additional device drivers by writing only the small amount of additional code required.

2. The 80150 is the most cost-effective way to implement CP/M-86 in a microcomputer. The integration of CP/M-86 with the 16K bytes of system memory it requires, the two boot ROMS required in a diskette-based CP/M-86, and the on-chip peripherals (interrupt controller and timers) lead to savings in software, parts cost, board space, and interconnect wiring.

3. The reliability of the microcomputer is increased significantly. Since CP/M-86 is now always in the system as a standard hardware operating system, a properly functioning system diskette is not required. CP/M-86 in hardware can no longer be overwritten accidentally by a runaway program. System reliability is enhanced by the decreased dependence on floppy disks and fewer chips and interconnections required by the highly integrated 80150.

4. The microcomputer system boots up CP/M-86 on power-on, rather than requiring the user to go through a complicated boot sequence, thus lowering the user expertise required.

5. Diskless CP/M-based systems are now easy to design. Since CP/M is already in the microcomputer hardware, there is no need for a disk drive in the system if it is not desired. Without a disk drive, a system is more portable, simpler to use, less costly, and more reliable.

6. The administrative costs associated with distributing CP/M-86 are eliminated. Since CP/M-86 is now resident on the 80150 in the microcomputer system, there is no end-user licensing required nor is there any serialization requirement for the 80150 (because no CP/M diskette is used).

7. End-users will value having their CP/M operating system resident in their computer rather than on a diskette. They will no longer have to back up the operating system or have a diskette working properly to bring the system up in CP/M, increasing their confidence in the integrity, reliability, and usability of the system.

80150 FUNCTIONAL DESCRIPTION

The 80150 is a processor extension that is fully compatible with the 8086, 8088, 80186, and 80188 microprocessors. When the 80150 is combined with the microprocessor, the two-chip set is called an Operating System Processor and is denoted as the iAPX 86/50, 88/50, 186/50, or 188/50. The basic system configuration is shown in Figure 1. The 80150 connects directly to the multiplexed address/data bus and runs up to 8 MHz without wait states.

A. Hardware. Figure 3 is a functional diagram of the 80150 itself. CP/M-86 is stored in the 16K-bytes of control store. The timers are compatible with the standard 8254 timer. The interrupt controller, with its eight programmable interrupt inputs and one interrupt output, is compatible with the 8259A Programmable Interrupt Controller. External slave 8259A inter-

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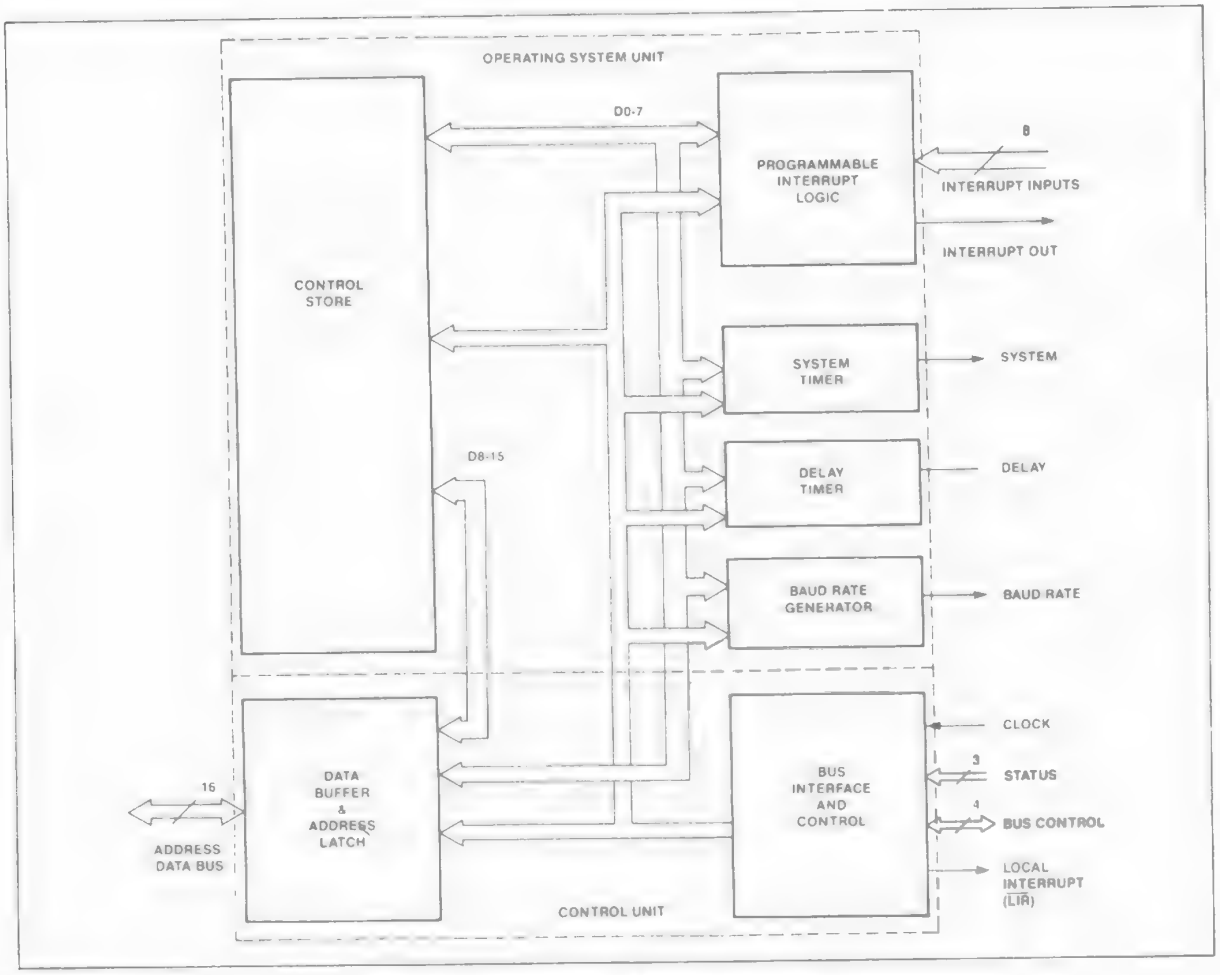


Figure 3. 80150 Internal Block Diagram

rupt controllers can be cascaded with the 80150 to expand the total number of interrupts to 57.

B. Software. Digital Research's version 1.1 of CP/M-86 forms the basis of the 80150. CP/M consists of three major parts: the Console Command Processor (CCP), the Basic Disk Operating System (BDOS), and the Basic Input/Output System (BIOS). Details on CP/M-86 are provided in Digital Research's *CP/M-86 Operating System User's Guide* and *CP/M-86 Operating System System Guide.*

CCP - Console Command Processor

The CCP provides all of the capabilities provided by Digital Research's CCP. Built-in commands have been expanded to include capabilities normally included as transient utilities on the Digital Research CP/M-86 diskette. Commands are provided to format diskettes, transfer files between devices (based on Digital Research's Peripheral Interchange Program PIP), and alter and display I/O device and file status (based on Digital Research's STAT).

Through User Intervention Points, the standard CP/M-86 CCP is enhanced to allow the user to add new built-in commands to further customize a CP/M-86 system.

BDOS - Basic Disk Operating System

Once the CCP has parsed a command, it sends it to the BDOS, which performs system services such as managing disk directories and files. Some of the standard BDOS functions provide:

- Console Status
- Console Input and Output
- List Output
- Select Drive
- Set Track and Sector

Read/Write Sector
Load Program

The BDOS in the 80150 provides the same functions as the standard Digital Research CP/M-86 BDOS.

BIOS - Basic Input/Output System

The BIOS contains the system-dependent I/O drivers. The 80150 BIOS offers two fundamental configuration options:

1. **A predefined configuration** which supports minimum cost CP/M-86 microcomputer systems and which requires no operating system development by the system designer.
2. **An OEM-configurable mode,** where the designer can choose among several drivers offered on the 80150 or substitute or add any additional device drivers of his choice.

These two options negate the potential software-on-silicon pitfall of inflexibility in system design. The OEM can customize the end system as desired.

The **predefined configuration** offers a choice among several peripheral chip drivers included on the 80150. Drivers for the following chips are included in the 80150 BIOS:

8251A	Universal Synchronous/ Asynchronous Receiver/Transmitter (USART)
8274	Multi-Protocol Serial Controller (MPSC)
8255A	Programmable Parallel Interface (PPI)
8275	CRT Controller
8272A	Floppy Disk Controller
8237A	DMA Controller (for use with 8275, 8272)

The following options are thus available:

CONSOLE OUT:	8251A, 8274, 8275
CONSOLE IN:	8251A, 8274, 8255A
LIST:	8251A, 8274, 8255A
AUXIN, AUXOUT:	8251A, 8274, 8255A
DISK:	8272

The actual configuration is detected by the 80150 on power-up. An example configuration is shown in Figure 4.

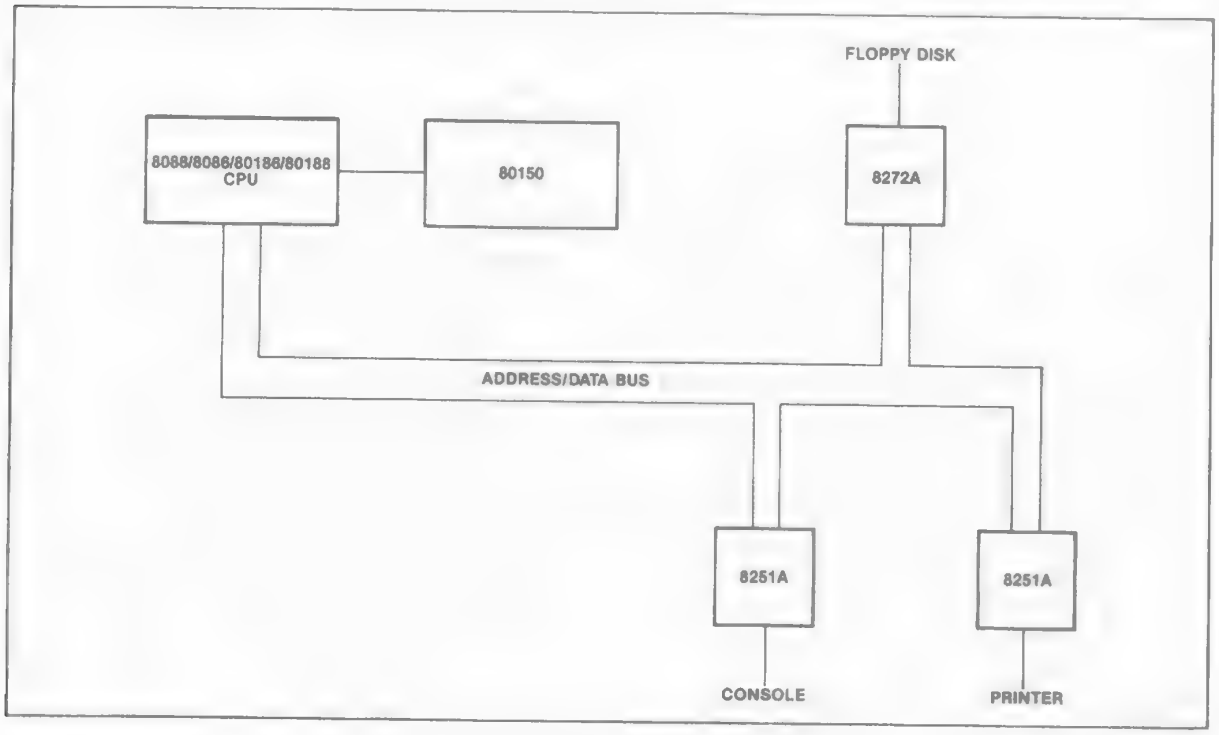


Figure 4. Predefined Configuration

Even in the predefined configuration, the system designer (or end user, if the system designer desires) may select parameters such as the baud rates for the console and printer, and the floppy disk size (standard 8″ or 5¼″ mini-floppy) and format (FM single density or MFM double density, single-sided or double-sided).

Drivers for the 80150 on-chip timers and interrupt controller are also included in the BIOS.

The 80150 takes advantage of the 80186 and 80188 on-chip peripherals in an iAPX 186/50 or 188/50 system. For example, the integrated DMA controller is used rather than an external 8237A. Also fully utilized are the integrated memory chip selects and I/O chip selects.

Since all microcomputer configurations cannot be anticipated, the **OEM-configurable mode** allows the system designer to use any set of peripheral chips desired. This configuration is shown in Figure 5.

By simply changing the jump addresses in a configuration table, the designer can also gain the flexibility of adding custom BIOS drivers for other peripheral chips, such as bubble memories or more complex CRT controllers. These drivers would be stored in memory external to the 80150 itself. By providing the configurability option, the 80150 is applicable to a far broader range of designs that it would be with an inflexible BIOS.

MEMORY ORGANIZATION

When using the **predefined configuration** of the 80150 BIOS, the 80150 must be placed in the top 16K of the address space of the microprocessor (starting at location FC000H) so that the 80150 gains control when the microprocessor is reset. Upon receipt of control, the 80150 writes a **configuration block** into the bottom 2K bytes of the microprocessor's address space, which must be in RAM. The 80150 uses the area after the interrupt vectors for system configuration information and scratch-pad storage.

When using the **OEM-configurable** mode of the 80150 BIOS, the 80150 is placed on any 16K boun-

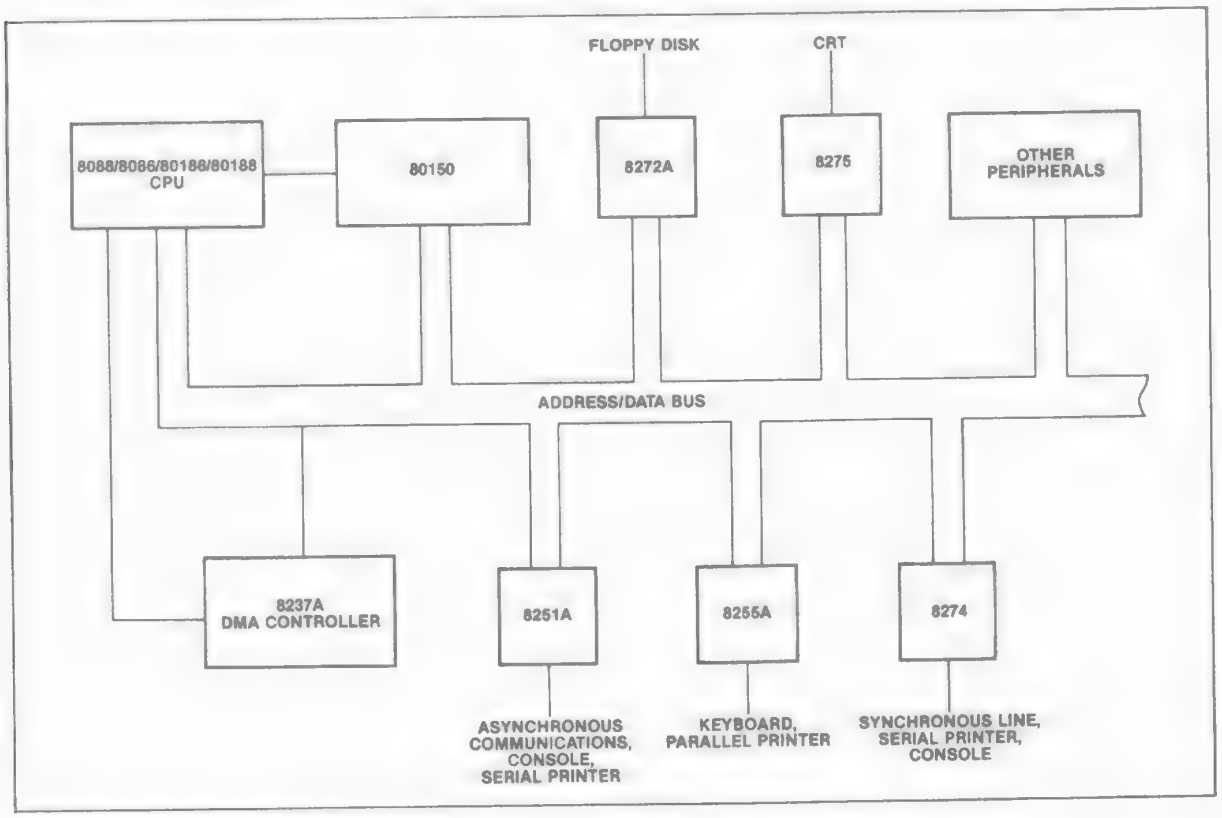


Figure 5. OEM Configurable System

dary of memory **except** the highest (FC000H) or lowest (00000H). The user writes interface code (in the form of a simple boot ROM) to incorporate and link additional features and changes into the standard 80150 environment. The configuration block may be located as desired in the address space, and its size may vary widely depending on the application.

Memory Disk

A unique capability offered by the 80150 is the Memory Disk. The Memory Disk consists of a block of RAM whose size can be selected by the designer. The Memory Disk is treated by the BDOS as any standard floppy disk, and is one of the 16 disks that CP/M can address. Thus files can be opened and closed, programs stored, and statistics gathered on the amount of Memory Disk space left.

The Memory Disk opens the possibility of a portable low-cost diskless microcomputer or network station. Applications software can be provided in a number of ways:

a. telephone lines via a modem.
b. ROM-based software.
c. a network.
d. bubble memory based software.
e. low-cost cassettes.

TYPICAL SYSTEM CONFIGURATION

Figure 6 shows the processing cluster of a "typical" iAPX 86/50 or iAPX 88/50 OSP system. Not shown are subsystems likely to vary with the application. The configuration includes an 8086 (or 8088) operating in maximum mode, an 8284A clock generator and an 8288 system controller. Note that the 80150 is located on the CPU side of any latches or transceivers.

Timers

The Timers are connected to the lower half of the data bus and are addressed at even addresses. The timers are read as two successive bytes,

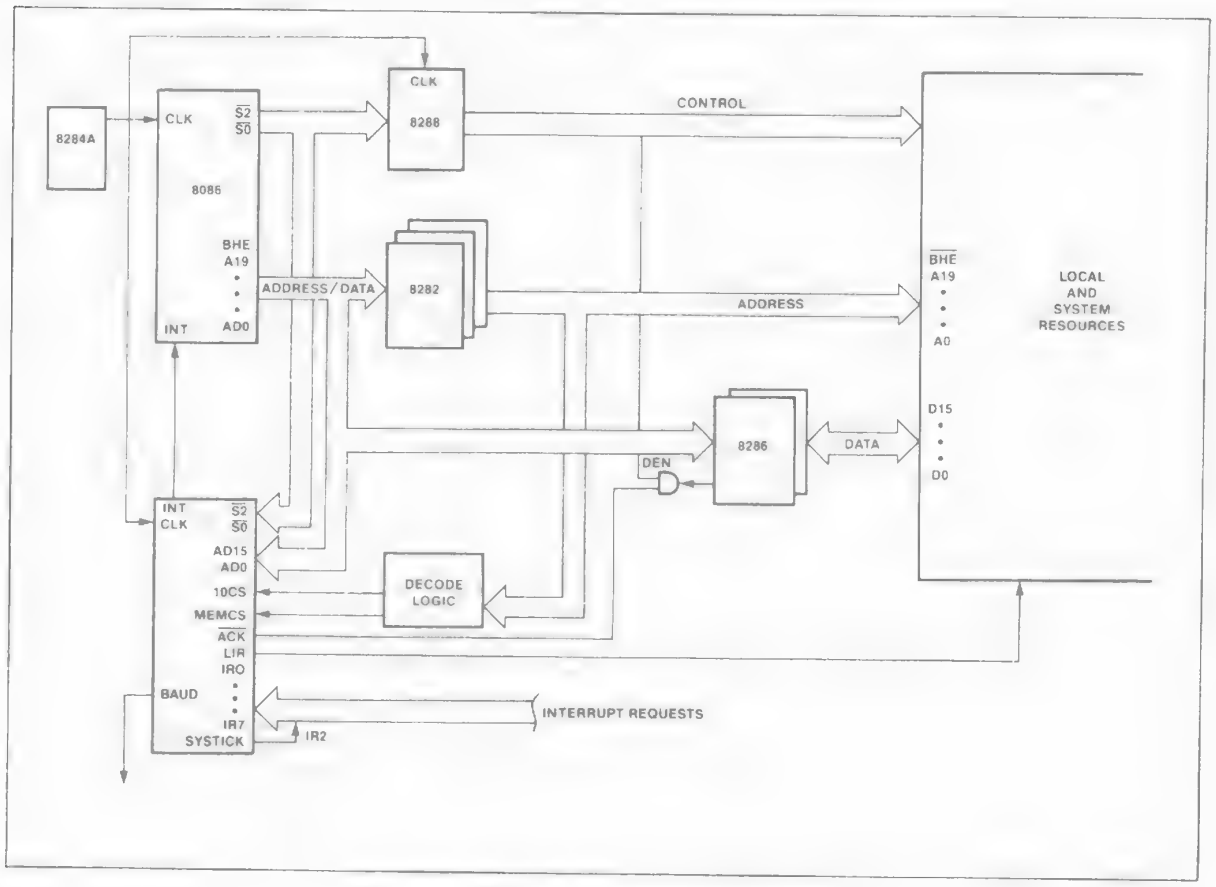


Figure 6. Typical OSP Configuration

AFN-01467B

always LSB followed by MSB. The MSB is always latched on a read operation and remains latched until read. Timers are not gatable. An external 8254 Programmable Interval Timer may be added to the system.

Baud Rate Generator

The baud rate generator operates like an 8254 (square wave mode 3). Its output, BAUD, is initially high and remains high until the Count Register is loaded. The first falling edge of the clock after the Count Register is loaded causes the transfer of the internal counter to the Count Register. The output stays high for N/2 [(N + 1)/2 if N is odd] and then goes low for N/2 [(N – 1)/2 if N is odd]. On the falling edge of the clock which signifies the final count for the output in low state, the output returns to high state and the Count Register is transferred to the internal counter. The baud rates can vary from 300 to 9600 baud.

The baud rate generator is located at 0CH (12), relative to the 16-byte boundary in the I/O space in which the 80150 component is located. The timer control word is located at relative address, 0EH(14). Timers are addressed with IOCS = 0. Timers 0 and 1 are assigned to use by the OSP, and should not be altered by the user.

The 80150 timers are subset compatible with 8254 timers.

Interrupt Controller

The Programmable Interrupt Controller (PIC), is also an integral unit of the 80150. Its eight input pins handle eight vectored priority interrupts. One of these pins must be used for the SYSTICK time function in timing waits, using an external connection as shown. During the 80150 initialization and configuration sequence, each 80150 interrupt pin is individually programmed as either level or edge sensitive. External slave 8259A interrupt controllers can be used to expand the total number of interrupts to 57.

In addition to standard PIC functions, the 80150 PIC unit has an $\overline{LIR}$ output signal, which when low indicates an interrupt acknowledge cycle. $\overline{LIR} = 0$ is provided to control the 8289 Bus Arbiter SYSB/$\overline{RESB}$ pin. This will avoid the need of requesting the system bus to acknowledge local bus non-slave interrupts. The user defines the interrupt system as part of the configuration.

INTERRUPT SEQUENCE

The interrupt sequence is as follows:

1. One or more of the interrupts is set by a low-to-high transition on edge-sensitive IR inputs or by a high input on level-sensitive IR inputs.
2. The 80150 evaluates these requests, and sends an INT to the CPU, if appropriate.
3. The CPU acknowledges the INT and responds with an interrupt acknowledge cycle which is encoded in $\overline{S_2} - \overline{S_0}$.
4. Upon receiving the first interrupt acknowledge from the CPU, the highest-priority interrupt is set by the 80150 and the corresponding edge detect latch is reset. The 80150 does not drive the address/data bus during this bus cycle but does acknowledge the cycle by making $\overline{ACK} = 0$ and sending the $\overline{LIR}$ value for the IR input being acknowledged.
5. The CPU will then initiate a second interrupt acknowledge cycle. During this cycle, the 80150 will supply the cascade address of the interrupting input at T_1 on the bus and also release an 8-bit pointer onto the bus if appropriate, where it is read by the CPU. If the 80150 does supply the pointer, then $\overline{ACK}$ will be low for the cycle. This cycle also has the value $\overline{LIR}$ for the IR input being acknowledged.
6. This completes the interrupt cycle. The ISR bit remains set until an appropriate EXIT INTERRUPT primitive (EOI command) is called at the end of the Interrupt Handler.

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to 150°C
Voltage on Any Pin With
Respect to Ground ..... −1.0V to +7V
Power Dissipation ..... 1.0 Watts

**NOTICE: Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended period may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 4.5 to 5.5V)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + .5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400 μA
I_{CC}	Power Supply Current		300	mA	T_A = 25 C
I_{LI}	Input Leakage Current		10	μA	$0 < V_{IN} < V_{CC}$
I_{LR}	IR Input Load Current		10 −300	μA μA	$V_{IN} = V_{CC}$ $V_{IN} = 0$
I_{LO}	Output Leakage Current		10	μA	$.45 = V_{IN} = V_{CC}$
V_{CLI}	Clock Input Low		0.6	V	
V_{CHI}	Clock Input High	3.9		V	
C_{IN}	Input Capacitance		10	pF	
C_{IO}	I/O Capacitance		15	pF	

A.C. CHARACTERISTICS (T_A = 0–70°C, V_{CC} = 4.5–5.5 Volt, V_{SS} = Ground)

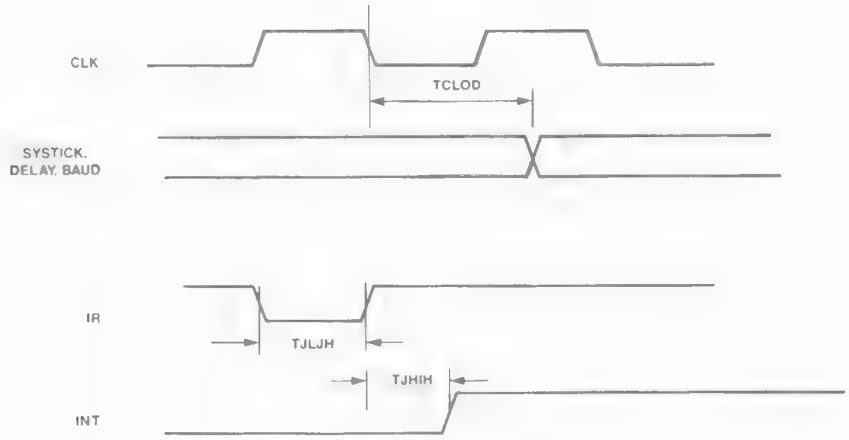
Symbol	Parameter	Min.	Max.	Units	Notes
T_{CLCL}	CLK Cycle Period	125	—	ns	C_L = 20–200 pF
T_{CLCH}	CLK Low Time	55	—	ns	
T_{CHCL}	CLK High Time	44	2000	ns	
T_{SVCH}	Status Active Setup Time	65	—	ns	
T_{CHSV}	Status Inactive Hold Time	10	—	ns	
T_{SHCL}	Status Inactive Setup Time	55	—	ns	
T_{CLSH}	Status Active Hold Time	10	—	ns	
T_{ASCH}	Address Valid Setup Time	8	—	ns	
T_{CLAH}	Address Hold Time	10	—	ns	
T_{CSCL}	Chip Select Setup Time	20	—	ns	
T_{CHCS}	Chip Select Hold Time	0	—	ns	
T_{DSCL}	Write Data Setup Time	60	—	ns	
T_{CHDH}	Write Data Hold Time	10	—	ns	
T_{JLJH}	IR Low Time	100	—	ns	
T_{ACC}	Read Data from Address	—	280	ns	
T_{CLDV}	Read Data Valid Delay	—	100	ns	
T_{CLDH}	Read Data Hold Time	10	—	ns	
T_{CLDX}	Read Data to Floating	10	100	ns	
T_{CLCA}	Cascade Address Delay Time	—	65	ns	
T_{IACA}	INTA Status to Cascade	—	65	ns	

A.C. CHARACTERISTICS (Continued)

Symbol	Parameter	Min.	Max.	Units	Notes
T_{CLCF}	Cascade Address Hold Time	10	—	ns	
T_{IAVE}	INTA Status to Acknowledge	—	80	ns	
T_{CHEH}	Acknowledge Hold Time	10	—	ns	
T_{CSAK}	Chip Select to ACK	—	110	ns	
T_{SACK}	Status to ACK	—	140	ns	
T_{AACK}	Address to ACK	—	90	ns	
T_{CLOD}	Timer Output Delay Time	—	200	ns	C_L = 100 pF
T_{CLOD1}	Timer1 Output Delay Time	—	T_{CLCL} + 200	ns	C_L = 100 pF
T_{JHIH}	INT Output Delay	—	T_{CLCL} + 200	ns	

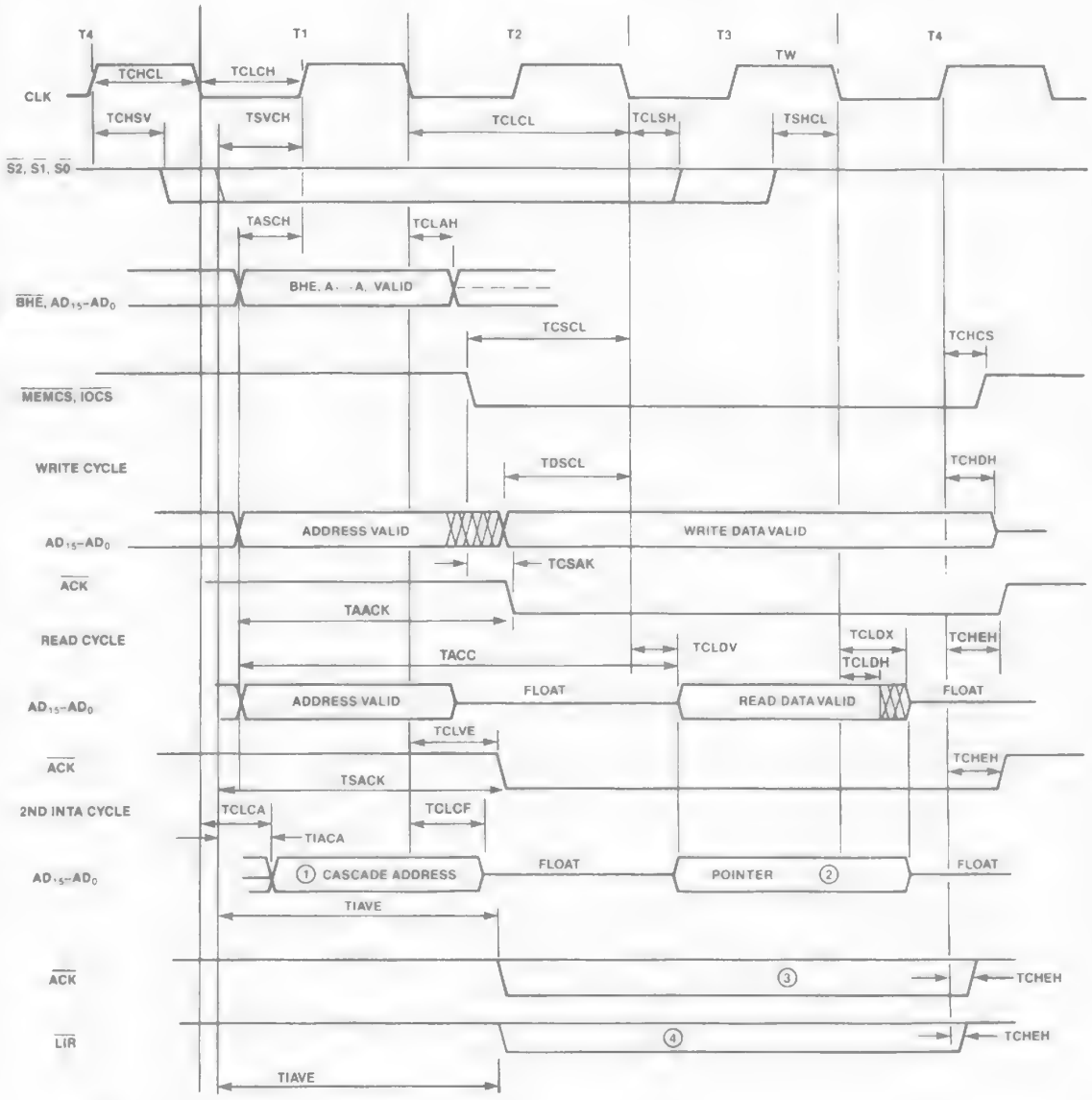
WAVEFORMS

A.C.



WAVEFORMS

D.C.



NOTES:
1. CASCADE ADDRESS PRESENTED ON AD8, AD9 AND AD10 CORRESPONDING TO CAS0, CAS1 AND CAS2 RESPECTIVELY. ALL OTHER AD LINES ARE ACTIVE AND HAVE UNKNOWN VALUES.
2. POINTER VALUE IS ACTIVE ONLY IF POINTER IS GENERATED FROM THE 80150 AND NOT FROM EXTERNAL SLAVE UNIT.
3. ACTIVE LOW ONLY WHEN POINTER DATA IS BEING SUPPLIED BY THE 80150.
4. LOW ONLY FOR LOCAL INTERRUPT.

8282/8283
OCTAL LATCH

- Address Latch for iAPX 86, 88, 186, 188, MCS-80®, MCS-85®, MCS-48® Famlies
- High Output Drive Capability for Driving System Data Bus
- Fully Parallel 8-Bit Data Register and Buffer
- Transparent during Active Strobe
- 3-State Outputs
- 20-Pin Package with 0.3" Center
- No Output Low Noise when Entering or Leaving High Impedance State
- Available in EXPRESS
  - Standard Temperature Range
  - Extended Temperature Range

The 8282 and 8283 are 8-bit bipolar latches with 3-state output buffers. They can be used to implement latches, buffers, or multiplexers. The 8283 inverts the input data at its outputs while the 8282 does not. Thus, all of the principal peripheral and input/output functions of a microcomputer system can be implemented with these devices.

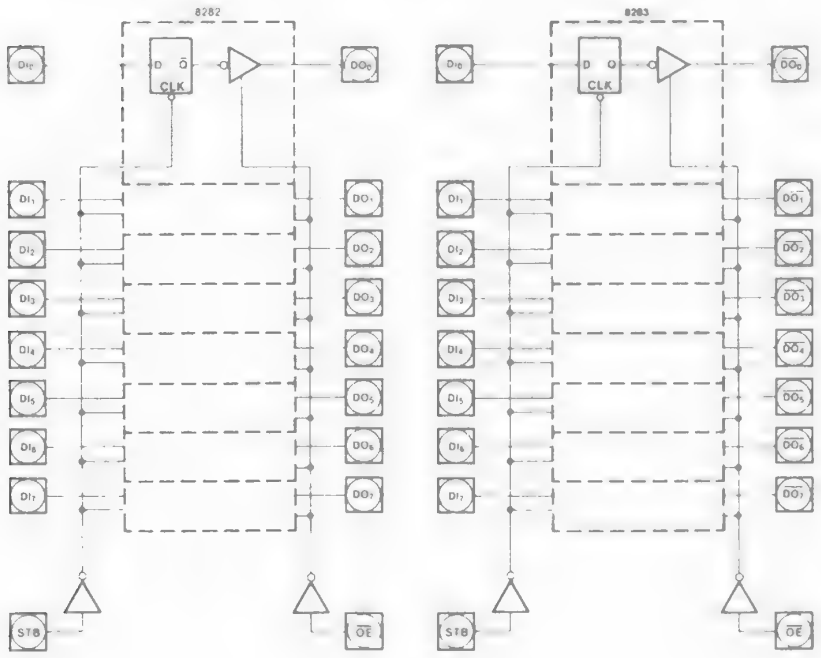


Figure 1. Logic Diagrams

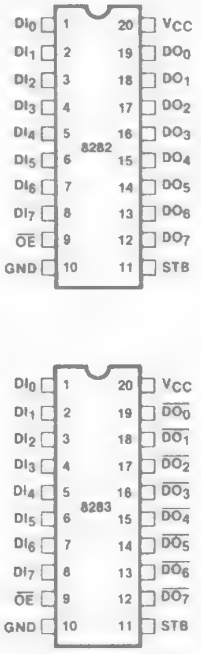


Figure 2. Pin Configurations

Table 1. Pin Description

Pin	Description
STB	STROBE (Input). STB is an input control pulse used to strobe data at the data input pins (A_0-A_7) into the data latches. This signal is active HIGH to admit input data. The data is latched at the HIGH to LOW transition of STB.
$\overline{OE}$	OUTPUT ENABLE (Input). $\overline{OE}$ is an input control signal which when active LOW enables the contents of the data latches onto the data output pin (B_0-B_7). OE being inactive HIGH forces the output buffers to their high impedance state.
DI_0-DI_7	DATA INPUT PINS (Input). Data presented at these pins satisfying setup time requirements when STB is strobed and latched into the data input latches.
DO_0-DO_7 (8282) $\overline{DO}_0$-$\overline{DO}_7$ (8283)	DATA OUTPUT PINS (Output). When $\overline{OE}$ is true, the data in the data latches is presented as inverted (8283) or non-inverted (8282) data onto the data output pins.

FUNCTIONAL DESCRIPTION

The 8282 and 8283 octal latches are 8-bit latches with 3-state output buffers. Data having satisfied the setup time requirements is latched into the data latches by strobing the STB line HIGH to LOW. Holding the STB line in its active HIGH state makes the latches appear transparent. Data is presented to the data output pins by activating the $\overline{OE}$ input line. When $\overline{OE}$ is inactive HIGH the output buffers are in their high impedance state. Enabling or disabling the output buffers will not cause negative-going transients to appear on the data output bus.

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias.....0°C to 70°C
Storage Temperature.....−65°C to +150°C
All Output and Supply Voltages.....−0.5V to +7V
All Input Voltages.....−1.0V to +5.5V
Power Dissipation.....1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (V_{CC} = 5V ±10%, T_A = 0°C to 70°C)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_C	Input Clamp Voltage		−1	V	I_C = −5 mA
I_{CC}	Power Supply Current		160	mA	
I_F	Forward Input Current		−0.2	mA	V_F = 0.45V
I_R	Reverse Input Current		50	μA	V_R = 5.25V
V_{OL}	Output Low Voltage		.45	V	I_{OL} = 32 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −5 mA
I_{OFF}	Output Off Current		±50	μA	V_{OFF} = 0.45 to 5.25V
V_{IL}	Input Low Voltage		0.8	V	V_{CC} = 5.0V See Note 1
V_{IH}	Input High Voltage	2.0		V	V_{CC} = 5.0V See Note 1
C_{IN}	Input Capacitance		12	pF	F = 1 MHz V_{BIAS} = 2.5V, V_{CC} = 5V T_A = 25°C

NOTE:
1. Output Loading I_{OL} = 32 mA, I_{OH} = −5 mA, C_L = 300 pF.*

A.C. CHARACTERISTICS (V_{CC} = 5V ±10%, T_A = 0°C to 70°C (See Note 2)
Loading: Outputs—I_{OL} = 32 mA, I_{OH} = −5 mA, C_L = 300 pF*)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
TIVOV	Input to Output Delay —Inverting —Non-Inverting	 5 5	 22 30	 ns ns	(See Note 1)
TSHOV	STB to Output Delay —Inverting —Non-Inverting	 10 10	 40 45	 ns ns	
TEHOZ	Output Disable Time	5	18	ns	
TELOV	Output Enable Time	10	30	ns	
TIVSL	Input to STB Setup Time	0		ns	
TSLIX	Input to STB Hold Time	25		ns	
TSHSL	STB High Time	15		ns	
TOLOH	Input, Output Rise Time		20	ns	From 0.8V to 2.0V
TOHOL	Input, Output Fall Time		12	ns	From 2.0V to 0.8V

*C_L = 200 pF for plastic 8282/8283.

NOTE:
1. See waveforms and test load circuit on following page.
2. For Extended Temperature EXPRESS the Preliminary Maximum Values are TIVOV = 25 vs 22, 35 vs 30; TSHOV = 45, 55; TEHOZ = 25; TELOV = 50.

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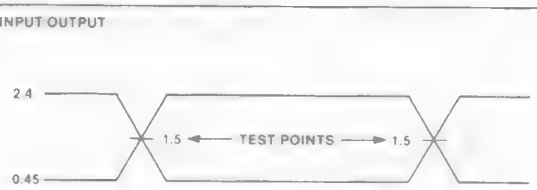
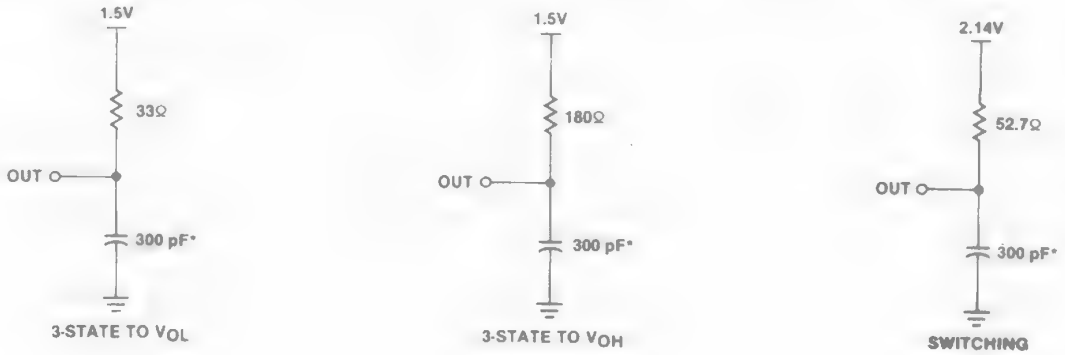
A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING: INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0." TIMING MEASUREMENTS ARE MADE AT 1.5V FOR BOTH A LOGIC "1" AND "0." INPUT RISE AND FALL TIMES ARE MEASURED FROM 0.8V TO 2.0V AND ARE DRIVEN AT 5ns ± 2ns.

OUTPUT TEST LOAD CIRCUITS



*200 pF for plastic 8282/8283.

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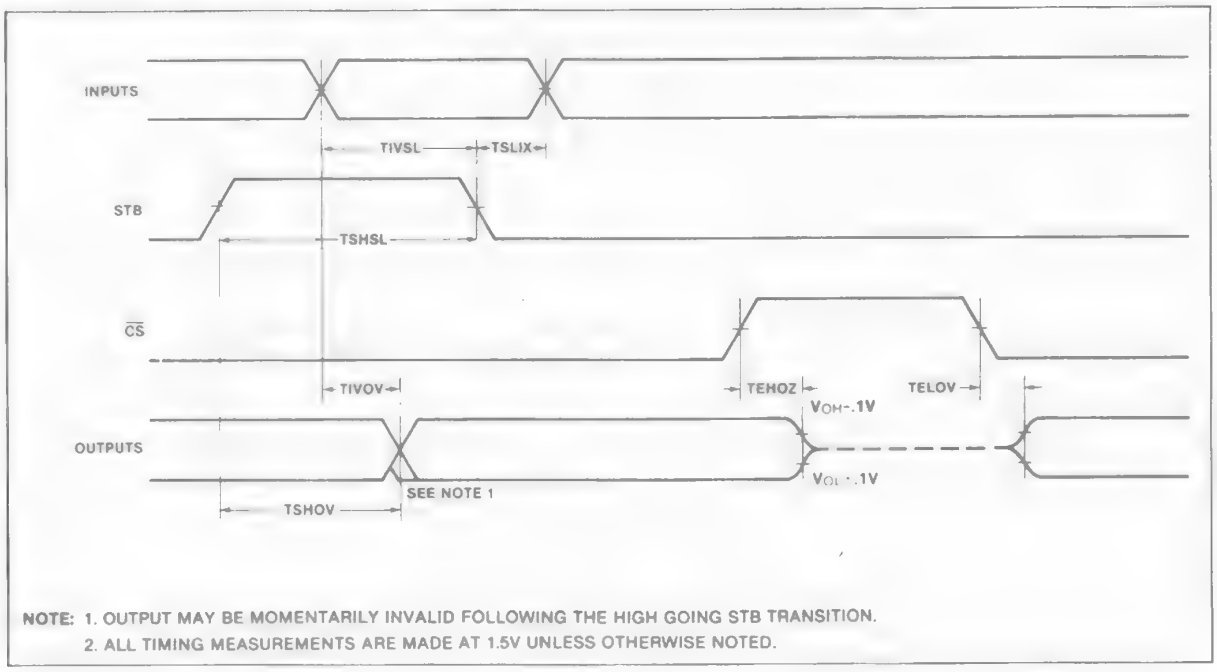
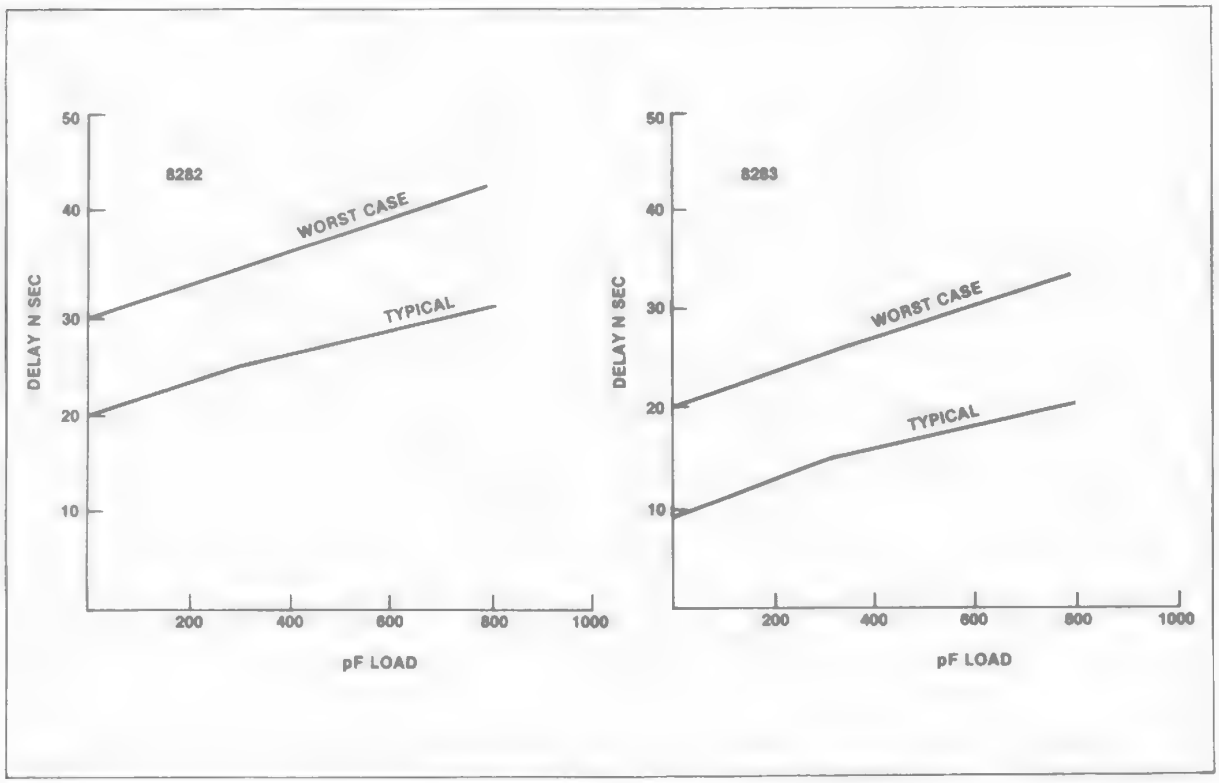
WAVEFORMS



NOTE: 1. OUTPUT MAY BE MOMENTARILY INVALID FOLLOWING THE HIGH GOING STB TRANSITION.
2. ALL TIMING MEASUREMENTS ARE MADE AT 1.5V UNLESS OTHERWISE NOTED.



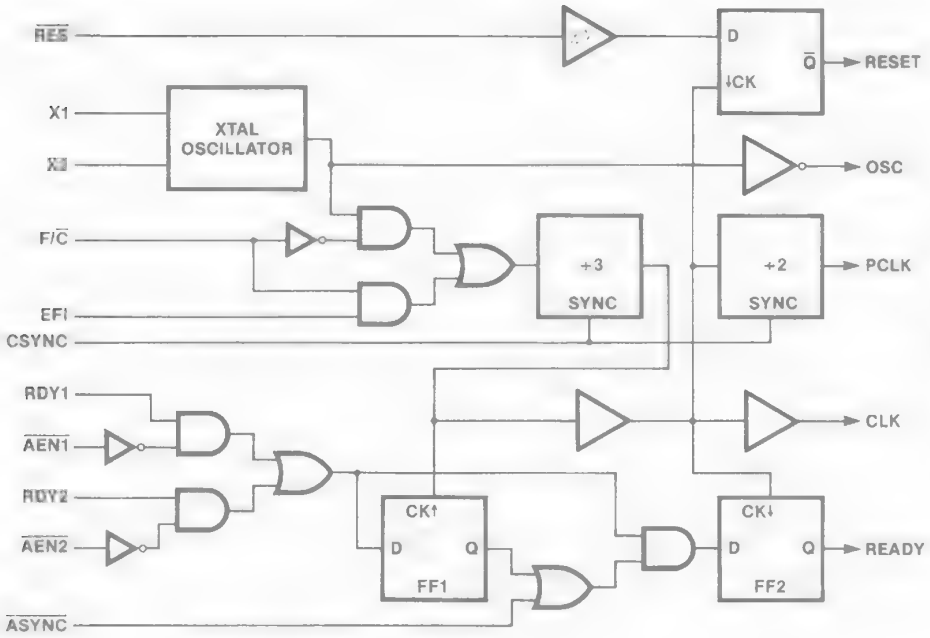
Output Delay vs. Capacitance

AFN-00727E

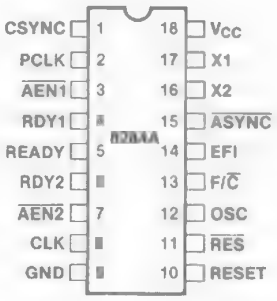
PRELIMINARY

8284A/8284A-1 CLOCK GENERATOR AND DRIVER FOR iAPX 86, 88 PROCESSORS

- Generates the System Clock for the iAPX 86, 88 Processors:
  5 MHz, 8 MHz with 8284A
  10 MHz with 8284A-1
- Uses a Crystal or a TTL Signal for Frequency Source
- Provides Local READY and Multibus™ READY Synchronization
- 18-Pin Package
- Single +5V Power Supply
- Generates System Reset Output from Schmitt Trigger Input
- Capable of Clock Synchronization with Other 8284As
- Available in EXPRESS
  - Standard Temperature Range
  - Extended Temperature Range



8284A/8284A-1 Block Diagram



8284A/8284A-1 Pin Configuration

Table 1. Pin Description

Symbol	Type	Name and Function
$\overline{AEN1}$, $\overline{AEN2}$	I	**Address Enable:** $\overline{AEN}$ is an active LOW signal. AEN serves to qualify its respective Bus Ready Signal (RDY1 or RDY2). $\overline{AEN1}$ validates RDY1 while $\overline{AEN2}$ validates RDY2. Two AEN signal inputs are useful in system configurations which permit the processor to access two Multi-Master System Busses. In non Multi-Master configurations the $\overline{AEN}$ signal inputs are tied true (LOW).
RDY1, RDY2	I	**Bus Ready:** (Transfer Complete). RDY is an active HIGH signal which is an indication from a device located on the system data bus that data has been received, or is available. RDY1 is qualified by $\overline{AEN1}$ while RDY2 is qualified by $\overline{AEN2}$.
$\overline{ASYNC}$	I	**Ready Synchronization Select:** $\overline{ASYNC}$ is an input which defines the synchronization mode of the READY logic. When $\overline{ASYNC}$ is low, two stages of READY synchronization are provided. When $\overline{ASYNC}$ is left open (internal pull-up resistor is provided) or HIGH a single stage of READY synchronization is provided.
READY	O	**Ready:** READY is an active HIGH signal which is the synchronized RDY signal input. READY is cleared after the guaranteed hold time to the processor has been met.
X1, X2	I	**Crystal In:** X1 and X2 are the pins to which a crystal is attached. The crystal frequency is 3 times the desired processor clock frequency.
F/$\overline{C}$	I	**Frequency/Crystal Select:** F/$\overline{C}$ is a strapping option. When strapped LOW, F/$\overline{C}$ permits the processor's clock to be generated by the crystal. When F/$\overline{C}$ is strapped HIGH, CLK is generated from the EFI input.
EFI	I	**External Frequency:** When F/$\overline{C}$ is strapped HIGH, CLK is generated from the input frequency appearing on this pin. The input signal is a square wave 3 times the frequency of the desired CLK output.
CLK	O	**Processor Clock:** CLK is the clock output used by the processor and all devices which directly connect to the processor's local bus (i.e., the bipolar support chips and other MOS devices). CLK has an output frequency which is ⅓ of the crystal or EFI input frequency and a ⅓ duty cycle. An output HIGH of 4.5 volts (V_{CC}= 5V) is provided on this pin to drive MOS devices.
PCLK	O	**Peripheral Clock:** PCLK is a TTL level peripheral clock signal whose output frequency is ½ that of CLK and has a 50% duty cycle.
OSC	O	**Oscillator Output:** OSC is the TTL level output of the internal oscillator circuitry. Its frequency is equal to that of the crystal.
$\overline{RES}$	I	**Reset In:** $\overline{RES}$ is an active LOW signal which is used to generate RESET. The 8284A provides a Schmitt trigger input so that an RC connection can be used to establish the power-up reset of proper duration.
RESET	O	**Reset:** RESET is an active HIGH signal which is used to reset the 8086 family processors. Its timing characteristics are determined by $\overline{RES}$.
CSYNC	I	**Clock Synchronization:** CSYNC is an active HIGH signal which allows multiple 8284As to be synchronized to provide clocks that are in phase. When CSYNC is HIGH the internal counters are reset. When CSYNC goes LOW the internal counters are allowed to resume counting. CSYNC needs to be externally synchronized to EFI. When using the internal oscillator CSYNC should be hardwired to ground.
GND		**Ground.**
V_{CC}		**Power:** +5V supply.

FUNCTIONAL DESCRIPTION

General

The 8284A is a single chip clock generator/driver for the iAPX 86, 88 processors. The chip contains a crystal-controlled oscillator, a divide-by-three counter, complete MULTIBUS™ "Ready" synchronization and reset logic. Refer to Figure 1 for Block Diagram and Figure 2 for Pin Configuration.

Oscillator

The oscillator circuit of the 8284A is designed primarily for use with an external series resonant, fundamental mode, crystal from which the basic operating frequency is derived.

The crystal frequency should be selected at three times the required CPU clock. X1 and X2 are the two crystal input crystal connections. For the most stable operation of the oscillator (OSC) output circuit, two series resistors ($R_1 = R_2 = 510\ \Omega$) as shown in the waveform figures are recommended. The output of the oscillator is buffered and brought out on OSC so that other system timing signals can be derived from this stable, crystal-controlled source.

For systems which have a V_{CC} ramp time ≥ 1V/ms and/or have inherent board capacitance between X1 or X2, exceeding 10 pF (not including 8284A pin capacitance), the two 510Ω resistors should be used. This circuit provides optimum stability for the oscillator in such extreme conditions. It is advisable to limit stray capacitances to less than 10 pF on X1 and X2 to minimize deviation from operating at the fundamental frequency.

Clock Generator

The clock generator consists of a synchronous divide-by-three counter with a special clear input that inhibits the counting. This clear input (CSYNC) allows the output clock to be synchronized with an external event (such as another 8284A clock). It is necessary to synchronize the CSYNC input to the EFI clock external to the 8284A. This is accomplished with two Schottky flip-flops. The counter output is a 33% duty cycle clock at one-third the input frequency.

The F/$\overline{C}$ input is a strapping pin that selects either the crystal oscillator or the EFI input as the clock for the ÷3 counter. If the EFI input is selected as the clock source, the oscillator section can be used independently for another clock source. Output is taken from OSC.

Clock Outputs

The CLK output is a 33% duty cycle MOS clock driver designed to drive the iAPX 86, 88 processors directly. PCLK is a TTL level peripheral clock signal whose output frequency is ½ that of CLK. PCLK has a 50% duty cycle.

Reset Logic

The reset logic provides a Schmitt trigger input ($\overline{RES}$) and a synchronizing flip-flop to generate the reset timing. The reset signal is synchronized to the falling edge of CLK. A simple RC network can be used to provide power-on reset by utilizing this function of the 8284A.

READY Synchronization

Two READY inputs (RDY1, RDY2) are provided to accommodate two Multi-Master system busses. Each input has a qualifier ($\overline{AEN1}$ and $\overline{AEN2}$, respectively). The $\overline{AEN}$ signals validate their respective RDY signals. If a Multi-Master system is not being used the $\overline{AEN}$ pin should be tied LOW.

Synchronization is required for all asynchronous active-going edges of either RDY input to guarantee that the RDY setup and hold times are met. Inactive-going edges of RDY in normally ready systems do not require synchronization but must satisfy RDY setup and hold as a matter of proper system design.

The $\overline{ASYNC}$ input defines two modes of READY synchronization operation.

When $\overline{ASYNC}$ is LOW, two stages of synchronization are provided for active READY input signals. Positive-going asynchronous READY inputs will first be synchronized to flip-flop one at the rising edge of CLK and then synchronized to flip-flop two at the next falling edge of CLK, after which time the READY output will go active (HIGH). Negative-going asynchronous READY inputs will be synchronized directly to flip-flop two at the falling edge of CLK, after which time the READY output will go inactive. This mode of operation is intended for use by asynchronous (normally not ready) devices in the system which cannot be guaranteed by design to meet the required RDY setup timing, T_{R1VCL}, on each bus cycle.

When $\overline{ASYNC}$ is high or left open, the first READY flip-flop is bypassed in the READY synchronization logic. READY inputs are synchronized by flip-flop two on the falling edge of CLK before they are presented to the processor. This mode is available for synchronous devices that can be guaranteed to meet the required RDY setup time.

$\overline{ASYNC}$ can be changed on every bus cycle to select the appropriate mode of synchronization for each device in the system.

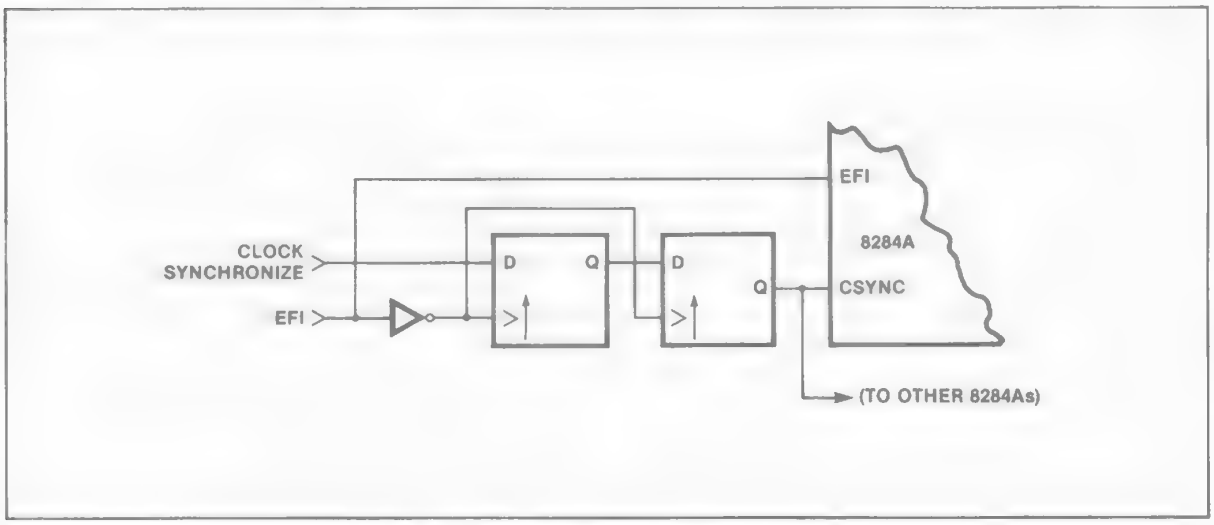


Figure 3. CSYNC Synchronization

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ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias . . . . . 0°C to 70°C
Storage Temperature . . . . . −65°C to +150°C
All Output and Supply Voltages . . . . . −0.5V to +7V
All Input Voltages . . . . . −1.0V to +5.5V
Power Dissipation . . . . . 1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS ($T_A = 0°C$ to $70°C$, $V_{CC} = 5V \pm 10\%$)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
I_F	Forward Input Current ($\overline{ASYNC}$) Other Inputs		−1.3 −0.5	mA mA	$V_F = 0.45V$ $V_F = 0.45V$
I_R	Reverse Input Current ($\overline{ASYNC}$) Other Inputs		50 50	μA μA	$V_R = V_{CC}$ $V_R = 5.25V$
V_C	Input Forward Clamp Voltage		−1.0	V	$I_C = -5mA$
I_{CC}	Power Supply Current		162	mA	
V_{IL}	Input LOW Voltage		0.8	V	
V_{IH}	Input HIGH Voltage	2.0		V	
V_{IHR}	Reset Input HIGH Voltage	2.6		V	
V_{OL}	Output LOW Voltage		0.45	V	5mA
V_{OH}	Output HIGH Voltage CLK Other Outputs	4 2.4		V V	−1mA −1mA
$V_{IHR} - V_{ILR}$	$\overline{RES}$ Input Hysteresis	0.25		V	

A.C. CHARACTERISTICS ($T_A = 0°C$ to $70°C$, $V_{CC} = 5V \pm 10\%$)

TIMING REQUIREMENTS

Symbol	Parameter	Min.	Max.	Units	Test Conditions
t_{EHEL}	External Frequency HIGH Time	13		ns	90%-90% V_{IN}
t_{ELEH}	External Frequency LOW Time	13		ns	10%-10% V_{IN}
t_{ELEL}	EFI Period	33		ns	(Note 1)
	XTAL Frequency	12	25	MHz	
t_{R1VCL}	RDY1, RDY2 Active Setup to CLK	35		ns	$\overline{ASYNC}$ = HIGH
t_{R1VCH}	RDY1, RDY2 Active Setup to CLK	35		ns	$\overline{ASYNC}$ = LOW
t_{R1VCL}	RDY1, RDY2 Inactive Setup to CLK	35		ns	
t_{CLR1X}	RDY1, RDY2 Hold to CLK	0		ns	
t_{AYVCL}	$\overline{ASYNC}$ Setup to CLK	50		ns	
t_{CLAYX}	$\overline{ASYNC}$ Hold to CLK	0		ns	
t_{A1VR1V}	$\overline{AEN1}$, $\overline{AEN2}$ Setup to RDY1, RDY2	15		ns	
t_{CLA1X}	$\overline{AEN1}$, $\overline{AEN2}$ Hold to CLK	0		ns	
t_{YHEH}	CSYNC Setup to EFI	20		ns	
t_{EHYL}	CSYNC Hold to EFI	10		ns	
t_{YHYL}	CSYNC Width	$2 \cdot t_{ELEL}$		ns	
t_{I1HCL}	$\overline{RES}$ Setup to CLK	65		ns	(Note 1)
t_{CLI1H}	$\overline{RES}$ Hold to CLK	20		ns	(Note 1)

A.C. CHARACTERISTICS (Continued)

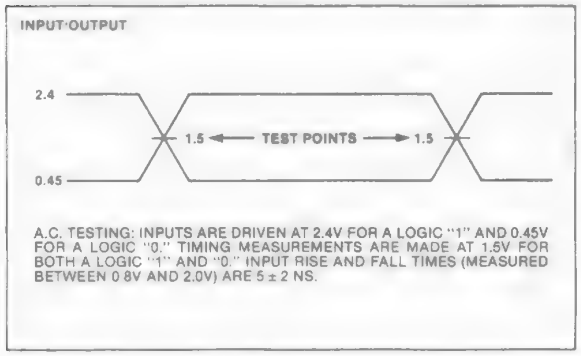
TIMING RESPONSES

Symbol	Parameter	Min. 8284A	Min. 8284A-1	Max.	Units	Test Conditions
t_{CLCL}	CLK Cycle Period	125	100		ns	
t_{CHCL}	CLK HIGH Time	$(1/3\ t_{CLCL})+2$	39		ns	
t_{CLCH}	CLK LOW Time	$(2/3\ t_{CLCL})-15$	53		ns	
t_{CH1CH2} t_{CL2CL1}	CLK Rise or Fall Time			10	ns	1.0V to 3.5V
t_{PHPL}	PCLK HIGH Time	$t_{CLCL}-20$	$t_{CLCL}-20$		ns	
t_{PLPH}	PCLK LOW Time	$t_{CLCL}-20$	$t_{CLCL}-20$		ns	
t_{RYLCL}	Ready Inactive to CLK (See Note 3)	−8	−8		ns	
t_{RYHCH}	Ready Active to CLK (See Note 2)	$(2/3\ t_{CLCL})-15$	53		ns	
t_{CLIL}	CLK to Reset Delay			40	ns	
t_{CLPH}	CLK to PCLK HIGH DELAY			22	ns	
t_{CLPL}	CLK to PCLK LOW Delay			22	ns	
t_{OLCH}	OSC to CLK HIGH Delay	−5	−5	22	ns	
t_{OLCL}	OSC to CLK LOW Delay	2	2	35	ns	
t_{OLOH}	Output Rise Time (except CLK)			20	ns	From 0.8V to 2.0V
t_{OHOL}	Output Fall Time (except CLK)			12	ns	From 2.0V to 0.8V

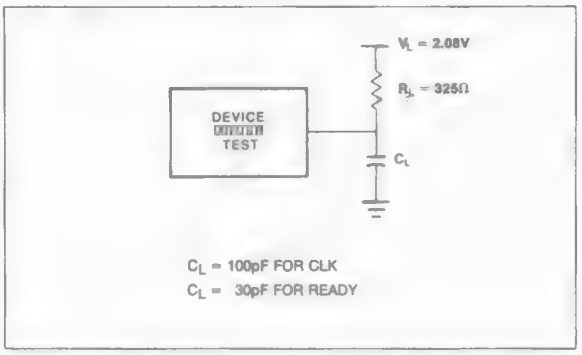
NOTES:

1. Setup and hold necessary only to guarantee recognition at next clock.
2. Applies only to T3 and TW states.
3. Applies only to T2 states.

A.C. TESTING INPUT, OUTPUT WAVEFORM



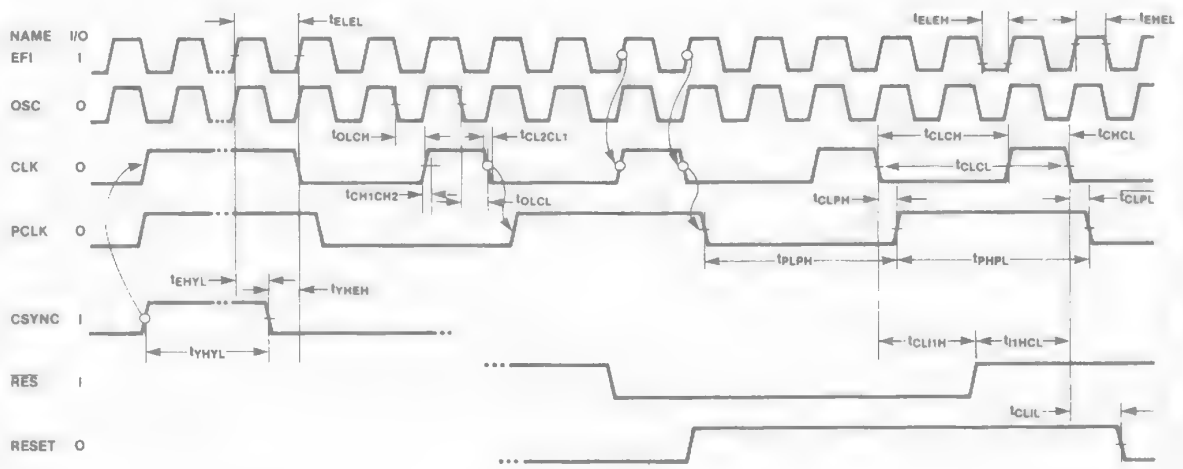
A.C. TESTING LOAD CIRCUIT



AFN-01472D

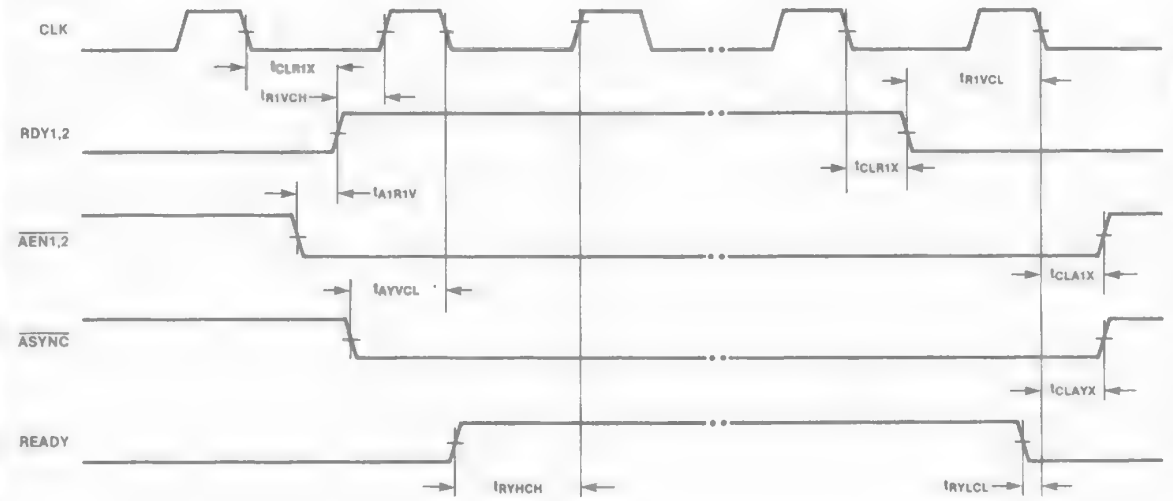
WAVEFORMS

CLOCKS AND RESET SIGNALS



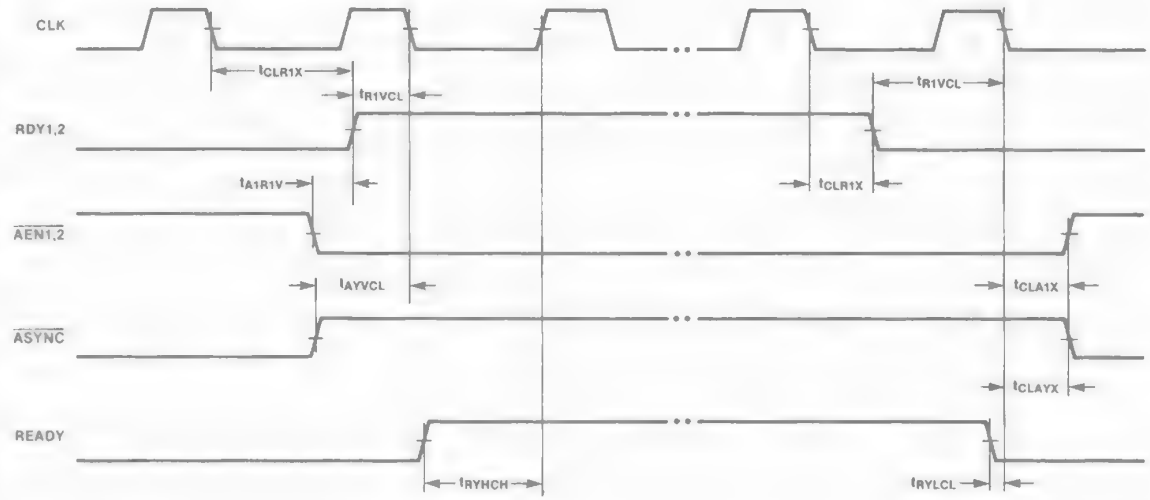
NOTE: ALL TIMING MEASUREMENTS ARE MADE AT 1.5 VOLTS, UNLESS OTHERWISE NOTED.

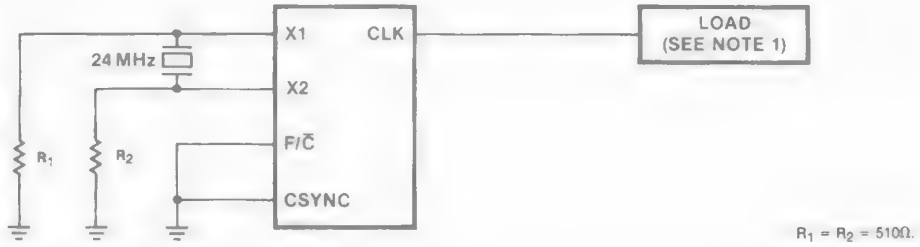
READY SIGNALS (FOR ASYNCHRONOUS DEVICES)



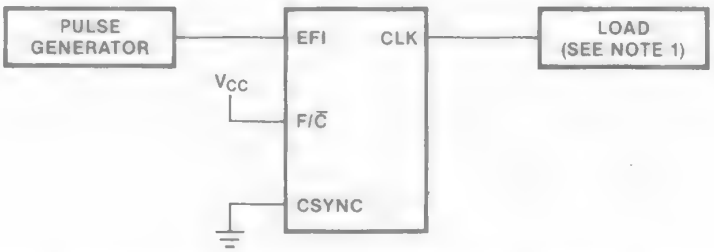
WAVEFORMS (Continued)

READY SIGNALS (FOR SYNCHRONOUS DEVICES)

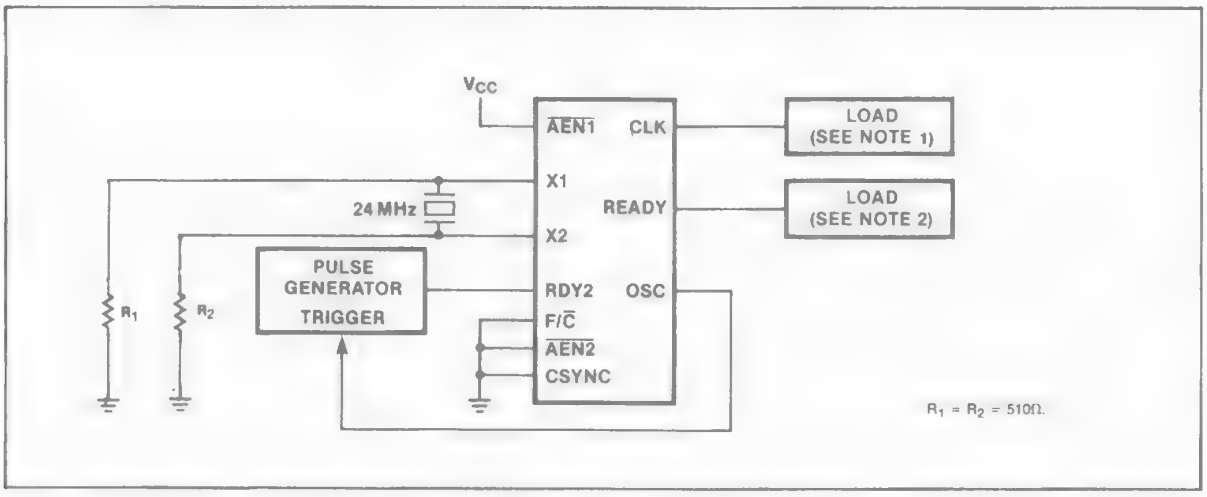




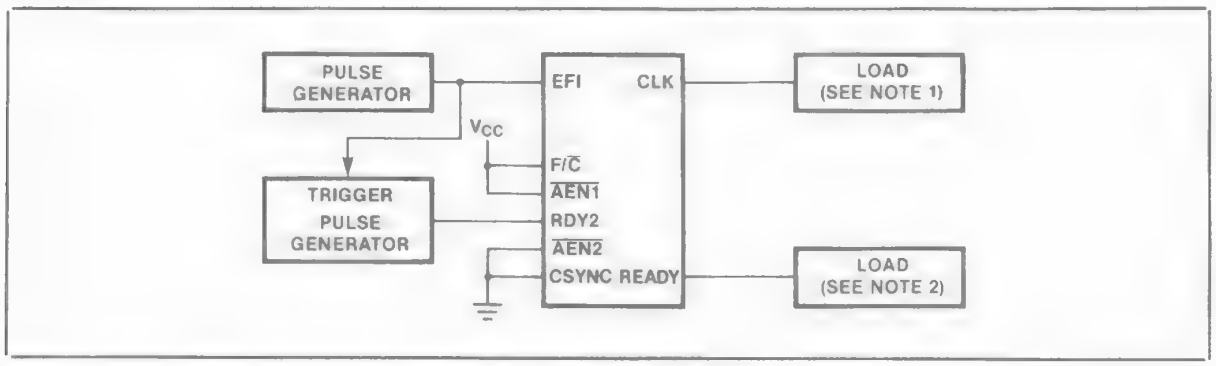
Clock High and Low Time (Using X1, X2)



Clock High and Low Time (Using EFI)



Ready to Clock (Using X1, X2)



Ready to Clock (Using EFI)

NOTES:
1. C_L = 100 pF
2. C_L = 30 pF

AFN-01472D

8286/8287
OCTAL BUS TRANSCEIVER

- Data Bus Buffer Driver for iAPX 86,88,186,188, MCS-80™, MCS-85™, and MCS-48™ Families
- High Output Drive Capability for Driving System Data Bus
- Fully Parallel 8-Bit Transceivers
- 3-State Outputs
- 20-Pin Package with 0.3" Center
- No Output Low Noise when Entering or Leaving High Impedance State
- Available in EXPRESS
  - Standard Temperature Range
  - Extended Temperature Range

The 8286 and 8287 are 8-bit bipolar transceivers with 3-state outputs. The 8287 inverts the input data at its outputs while the 8286 does not. Thus, a wide variety of applications for buffering in microcomputer systems can be met.

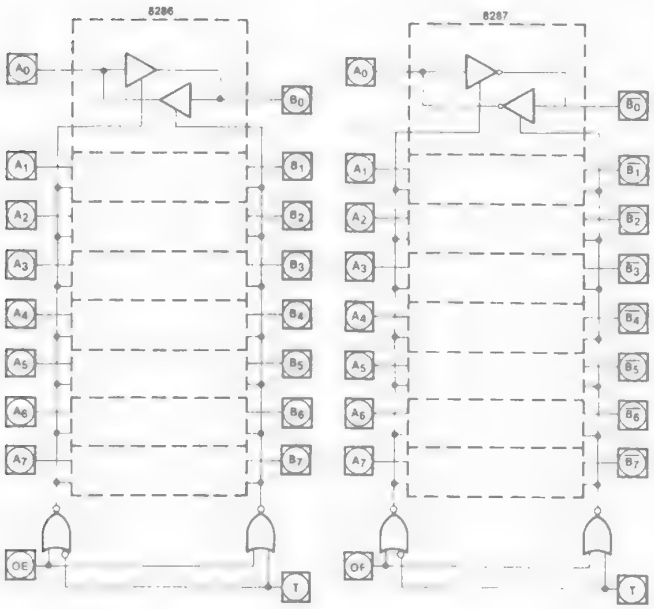


Figure 1. Logic Diagrams

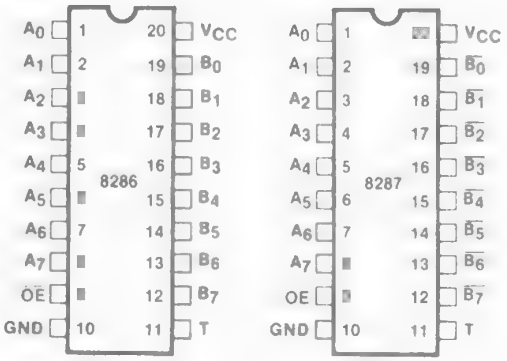


Figure 2. Pin Configurations

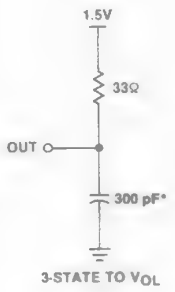
Table 1. Pin Description

Symbol	Type	Name and Function
T	I	**Transmit:** T is an input control signal used to control the direction of the transceivers. When HIGH, it configures the transceiver's B_0–B_7 as outputs with A_0–A_7 as inputs. T LOW configures A_0–A_7 as the outputs with B_0–B_7 serving as the inputs.
$\overline{OE}$	I	**Output Enable:** $\overline{OE}$ is an input control signal used to enable the appropriate output driver (as selected by T) onto its respective bus. This signal is active LOW.
A_0–A_7	I/O	**Local Bus Data Pins:** These pins serve to either present data to or accept data from the processor's local bus depending upon the state of the T pin.
B_0–B_7(8286) $\overline{B_0}$–$\overline{B_7}$(8287)	I/O	**System Bus Data Pins:** These pins serve to either present data to or accept data from the system bus depending upon the state of the T pin.

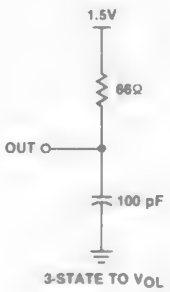
FUNCTIONAL DESCRIPTION

The 8286 and 8287 transceivers are 8-bit transceivers with high impedance outputs. With T active HIGH and $\overline{OE}$ active LOW, data at the A_0–A_7 pins is driven onto the B_0–B_7 pins. With T inactive LOW and $\overline{OE}$ active LOW, data at the B_0–B_7 pins is driven onto the A_0–A_7 pins. No output low glitching will occur whenever the transceivers are entering or leaving the high impedance state.

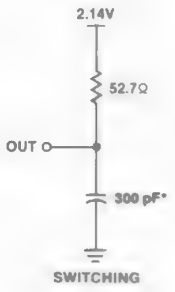
TEST LOAD CIRCUITS



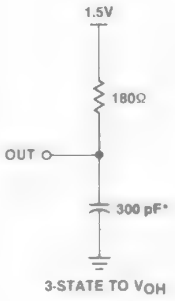
B OUTPUT



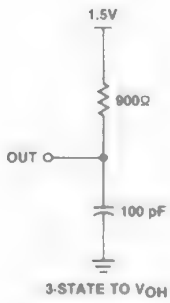
A OUTPUT



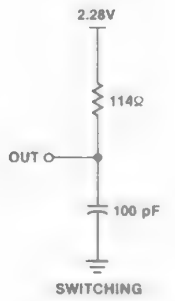
B OUTPUT



B OUTPUT



A OUTPUT



A OUTPUT

*200 pF for plastic 8286/8287

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias.....0°C to 70°C
Storage Temperature.....−65°C to +150°C
All Output and Supply Voltages.....−0.5V to +7V
All Input Voltages.....−1.0V to +5.5V
Power Dissipation.....1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (V_{CC} = +5V ±10%, T_A = 0°C to 70°C)

Symbol	Parameter	Min	Max	Units	Test Conditions
V_C	Input Clamp Voltage		-1	V	I_C = -5 mA
I_{CC}	Power Supply Current—8287 —8286		130 160	mA mA	
I_F	Forward Input Current		-0.2	mA	V_F = 0.45V
I_R	Reverse Input Current		50	μA	V_R = 5.25V
V_{OL}	Output Low Voltage —B Outputs —A Outputs		.45 .45	V V	I_{OL} = 32 mA I_{OL} = 16 mA
V_{OH}	Output High Voltage —B Outputs —A Outputs	2.4 2.4		V V	I_{OH} = -5 mA I_{OH} = -1 mA
I_{OFF} I_{OFF}	Output Off Current Output Off Current		I_F I_R		V_{OFF} = 0.45V V_{OFF} = 5.25V
V_{IL}	Input Low Voltage —A Side —B Side		0.8 0.9	V V	V_{CC} = 5.0V, See Note 1 V_{CC} = 5.0V, See Note 1
V_{IH}	Input High Voltage	2.0		V	V_{CC} = 5.0V, See Note 1
C_{IN}	Input Capacitance		12	pF	F = 1 MHz V_{BIAS} = 2.5V, V_{CC} = 5V T_A = 25°C

NOTE:
1. B Outputs—I_{OL} = 32 mA, I_{OH} = −5 mA, C_L = 300 pF*: A Outputs—I_{OL} = 16 mA, I_{OH} = −1 mA, C_L = 100 pF.

A.C. CHARACTERISTICS (V_{CC} = +5V ±10%, T_A = 0°C to 70°C) (See Note 2)

Loading: B Outputs—I_{OL} = 32 mA, I_{OH} = −5 mA, C_L = 300 pF*
A Outputs—I_{OL} = 16 mA, I_{OH} = −1 mA, C_L = 100 pF

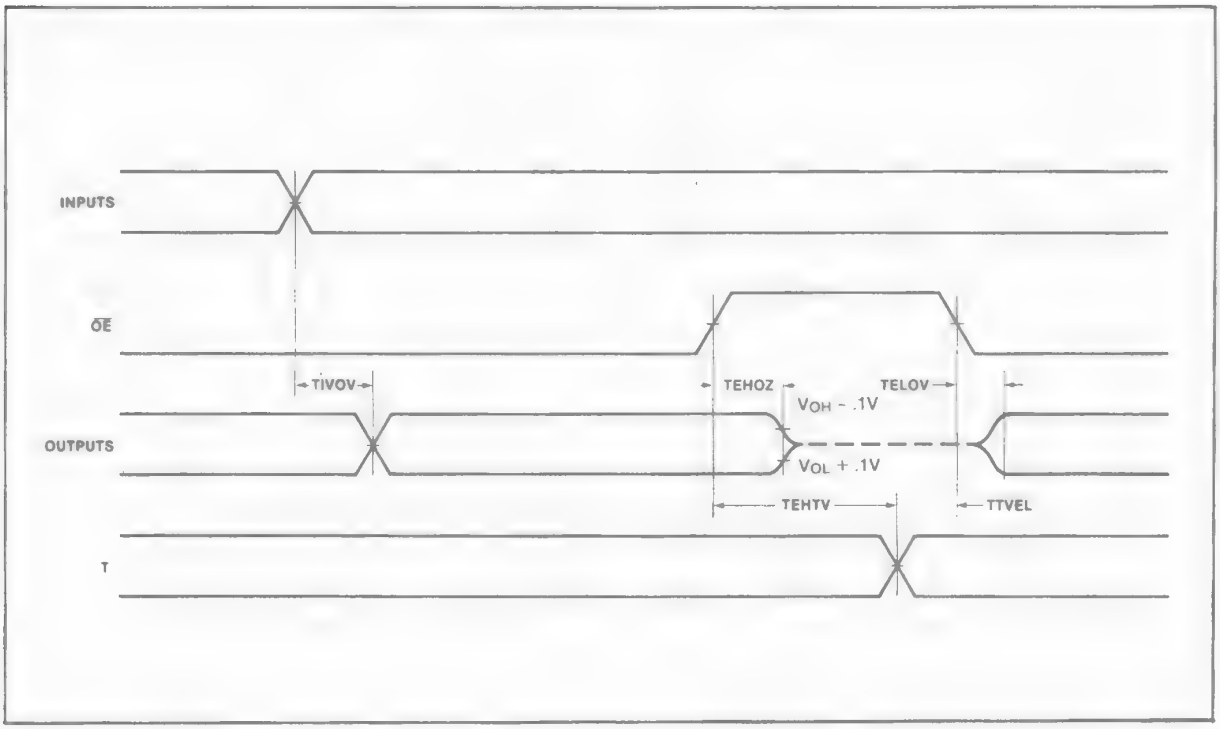
Symbol	Parameter	Min	Max	Units	Test Conditions
TIVOV	Input to Output Delay Inverting Non-Inverting	 5 5	 22 30	 ns ns	(See Note 1)
TEHTV	Transmit/Receive Hold Time	5		ns	
TTVEL	Transmit/Receive Setup	10		ns	
TEHOZ	Output Disable Time	5	18	ns	
TELOV	Output Enable Time	10	30	ns	
TOLOH	Input, Output Rise Time		20	ns	From 0.8 V to 2.0V
TOHOL	Input, Output Fall Time		12	ns	From 2.0V to 8.0V

*C_L = 200 pF for plastic 8286/8287

NOTE:
1. See waveforms and test load circuit on following page.
2. For Extended Temperature EXPRESS the Preliminary Maximum Values are TIVOV = 25 vs 22, 35 vs 30; TEHOZ = 25; TELOV = 50.

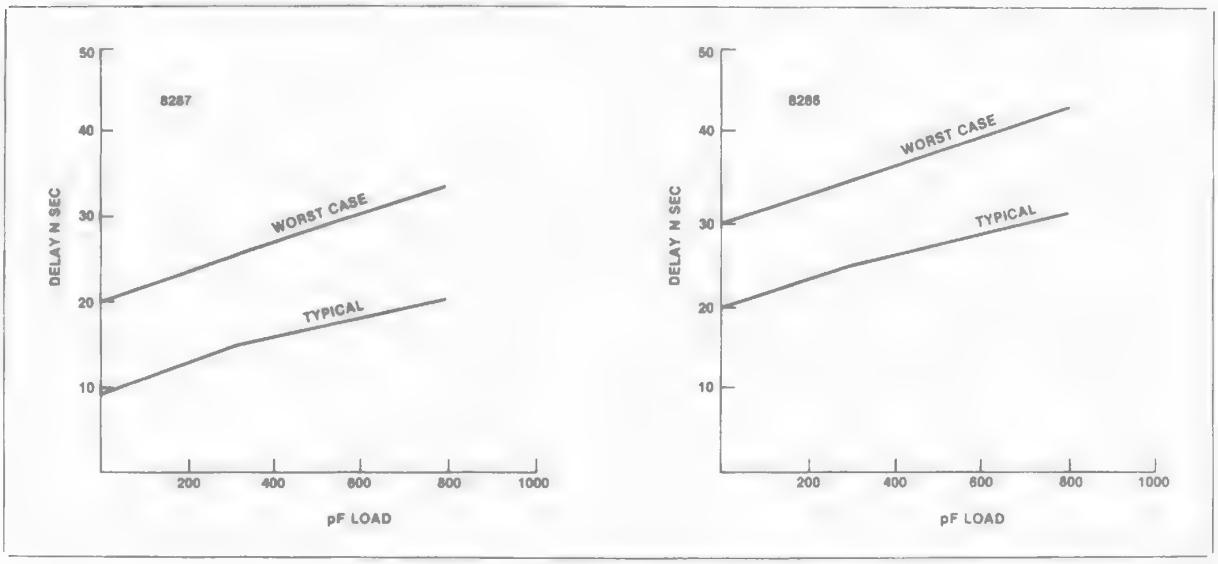
AFN-01506D

WAVEFORMS



NOTE:

1. All timing measurements are made at 1.5V unless otherwise noted.



Output Delay versus Capacitance

AFN-01506D

8288
BUS CONTROLLER
FOR iAPX 86, 88 PROCESSORS

- **Bipolar Drive Capability**
- **Provides Advanced Commands**
- **Provides Wide Flexibility in System Configurations**
- **3-State Command Output Drivers**
- **Configurable for Use with an I/O Bus**
- **Facilitates Interface to One or Two Multi-Master Busses**
- **Available in EXPRESS**
  - **Standard Temperature Range**
  - **Extended Temperature Range**

The Intel® 8288 Bus Controller is a 20-pin bipolar component for use with medium-to-large iAPX 86, 88 processing systems. The bus controller provides command and control timing generation as well as bipolar bus drive capability while optimizing system performance.

A strapping option on the bus controller configures it for use with a multi-master system bus and separate I/O bus.

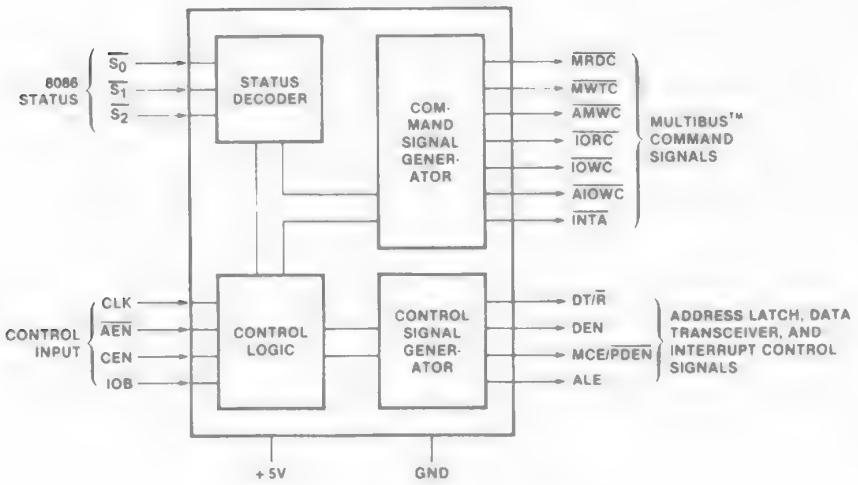


Figure 1. Block Diagram

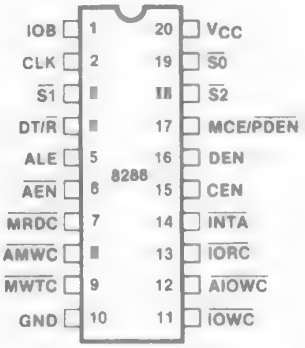


Figure 2. Pin Configuration

Table 1. Pin Description

Symbol	Type	Name and Function
V_{CC}		**Power:** +5V supply.
GND		**Ground.**
$\overline{S_0}$, $\overline{S_1}$, $\overline{S_2}$	I	**Status Input Pins:** These pins are the status input pins from the 8086, 8088 or 8089 processors. The 8288 decodes these inputs to generate command and control signals at the appropriate time. When these pins are not in use (passive) they are all HIGH. (See chart under Command and Control Logic.)
CLK	I	**Clock:** This is a clock signal from the 8284 clock generator and serves to establish when command and control signals are generated.
ALE	O	**Address Latch Enable:** This signal serves to strobe an address into the address latches. This signal is active HIGH and latching occurs on the falling (HIGH to LOW) transition. ALE is intended for use with transparent D type latches.
DEN	O	**Data Enable:** This signal serves to enable data transceivers onto either the local or system data bus. This signal is active HIGH.
DT/$\overline{R}$	O	**Data Transmit/Receive:** This signal establishes the direction of data flow through the transceivers. A HIGH on this line indicates Transmit (write to I/O or memory) and a LOW indicates Receive (Read).
$\overline{AEN}$	I	**Address Enable:** $\overline{AEN}$ enables command outputs of the 8288 Bus Controller at least 115 ns after it becomes active (LOW). $\overline{AEN}$ going inactive immediately 3-states the command output drivers. $\overline{AEN}$ does not affect the I/O command lines if the 8288 is in the I/O Bus mode (IOB tied HIGH).
CEN	I	**Command Enable:** When this signal is LOW all 8288 command outputs and the DEN and $\overline{PDEN}$ control outputs are forced to their inactive state. When this signal is HIGH, these same outputs are enabled.
IOB	I	**Input/Output Bus Mode:** When the IOB is strapped HIGH the 8288 functions in the I/O Bus mode. When it is strapped LOW, the 8288 functions in the System Bus mode. (See sections on I/O Bus and System Bus modes).

Symbol	Type	Name and Function
$\overline{AIOWC}$	O	**Advanced I/O Write Command:** The $\overline{AIOWC}$ issues an I/O Write Command earlier in the machine cycle to give I/O devices an early indication of a write instruction. Its timing is the same as a read command signal. $\overline{AIOWC}$ is active LOW.
$\overline{IOWC}$	O	**I/O Write Command:** This command line instructs an I/O device to read the data on the data bus. This signal is active LOW.
$\overline{IORC}$	O	**I/O Read Command:** This command line instructs an I/O device to drive its data onto the data bus. This signal is active LOW.
$\overline{AMWC}$	O	**Advanced Memory Write Command:** The $\overline{AMWC}$ issues a memory write command earlier in the machine cycle to give memory devices an early indication of a write instruction. Its timing is the same as a read command signal. $\overline{AMWC}$ is active LOW.
$\overline{MWTC}$	O	**Memory Write Command:** This command line instructs the memory to record the data present on the data bus. This signal is active LOW.
$\overline{MRDC}$	O	**Memory Read Command:** This command line instructs the memory to drive its data onto the data bus. This signal is active LOW.
$\overline{INTA}$	O	**Interrupt Acknowledge:** This command line tells an interrupting device that its interrupt has been acknowledged and that it should drive vectoring information onto the data bus. This signal is active LOW.
MCE/$\overline{PDEN}$	O	This is a dual function pin. **MCE (IOB is tied LOW):** Master Cascade Enable occurs during an interrupt sequence and serves to read a Cascade Address from a master PIC (Priority Interrupt Controller) onto the data bus. The MCE signal is active HIGH. **$\overline{PDEN}$ (IOB is tied HIGH):** Peripheral Data Enable enables the data bus transceiver for the I/O bus that DEN performs for the system bus. $\overline{PDEN}$ is active LOW.

FUNCTIONAL DESCRIPTION

Command and Control Logic

The command logic decodes the three 8086, 8088 or 8089 CPU status lines ($\overline{S_0}$, $\overline{S_1}$, $\overline{S_2}$) to determine what command is to be issued.

This chart shows the meaning of each status "word".

$\overline{S_2}$	$\overline{S_1}$	$\overline{S_0}$	Processor State	8288 Command
0	0	0	Interrupt Acknowledge	$\overline{INTA}$
0	0	1	Read I/O Port	$\overline{IORC}$
0	1	0	Write I/O Port	$\overline{IOWC}$,$\overline{AIOWC}$
0	1	1	Halt	None
1	0	0	Code Access	$\overline{MRDC}$
1	0	1	Read Memory	$\overline{MRDC}$
1	1	0	Write Memory	$\overline{MWTC}$,$\overline{AMWC}$
1	1	1	Passive	None

The command is issued in one of two ways dependent on the mode of the 8288 Bus Controller.

I/O Bus Mode — The 8288 is in the I/O Bus mode if the IOB pin is strapped HIGH. In the I/O Bus mode all I/O command lines ($\overline{IORC}$, $\overline{IOWC}$, $\overline{AIOWC}$, $\overline{INTA}$) are always enabled (i.e., not dependent on $\overline{AEN}$). When an I/O command is initiated by the processor, the 8288 immediately activates the command lines using $\overline{PDEN}$ and DT/$\overline{R}$ to control the I/O bus transceiver. The I/O command lines should not be used to control the system bus in this configuration because no arbitration is present. This mode allows one 8288 Bus Controller to handle two external busses. No waiting is involved when the CPU wants to gain access to the I/O bus. Normal memory access requires a "Bus Ready" signal ($\overline{AEN}$ LOW) before it will proceed. It is advantageous to use the IOB mode if I/O or peripherals dedicated to one processor exist in a multi-processor system.

System Bus Mode — The 8288 is in the System Bus mode if the IOB pin is strapped LOW. In this mode no command is issued until 115 ns after the $\overline{AEN}$ Line is activated (LOW). This mode assumes bus arbitration logic will inform the bus controller (on the $\overline{AEN}$ line) when the bus is free for use. Both memory and I/O commands wait for bus arbitration. This mode is used when only one bus exists. Here, both I/O and memory are shared by more than one processor.

COMMAND OUTPUTS

The advanced write commands are made available to initiate write procedures early in the machine cycle. This signal can be used to prevent the processor from entering an unnecessary wait state.

The command outputs are:

- $\overline{MRDC}$ — Memory Read Command
- $\overline{MWTC}$ — Memory Write Command
- $\overline{IORC}$ — I/O Read Command
- $\overline{IOWC}$ — I/O Write Command
- $\overline{AMWC}$ — Advanced Memory Write Command
- $\overline{AIOWC}$ — Advanced I/O Write Command
- $\overline{INTA}$ — Interrupt Acknowledge

$\overline{INTA}$ (Interrupt Acknowledge) acts as an I/O read during an interrupt cycle. Its purpose is to inform an interrupting device that its interrupt is being acknowledged and that it should place vectoring information onto the data bus.

CONTROL OUTPUTS

The control outputs of the 8288 are Data Enable (DEN), Data Transmit/Receive (DT/$\overline{R}$) and Master Cascade Enable/Peripheral Data Enable (MCE/$\overline{PDEN}$). The DEN signal determines when the external bus should be enabled onto the local bus and the DT/$\overline{R}$ determines the direction of data transfer. These two signals usually go to the chip select and direction pins of a transceiver.

The MCE/$\overline{PDEN}$ pin changes function with the two modes of the 8288. When the 8288 is in the IOB mode (IOB HIGH) the $\overline{PDEN}$ signal serves as a dedicated data enable signal for the I/O or Peripheral System bus.

INTERRUPT ACKNOWLEDGE AND MCE

The MCE signal is used during an interrupt acknowledge cycle if the 8288 is in the System Bus mode (IOB LOW). During any interrupt sequence there are two interrupt acknowledge cycles that occur back to back. During the first interrupt cycle no data or address transfers take place. Logic should be provided to mask off MCE during this cycle. Just before the second cycle begins the MCE signal gates a master Priority Interrupt Controller's (PIC) cascade address onto the processor's local bus where ALE (Address Latch Enable) strobes it into the address latches. On the leading edge of the second interrupt cycle the addressed slave PIC gates an interrupt vector onto the system data bus where it is read by the processor.

If the system contains only one PIC, the MCE signal is not used. In this case the second Interrupt Acknowledge signal gates the interrupt vector onto the processor bus.

ADDRESS LATCH ENABLE AND HALT

Address Latch Enable (ALE) occurs during each machine cycle and serves to strobe the current address into the address latches. ALE also serves to strobe the status ($\overline{S_0}$, $\overline{S_1}$, $\overline{S_2}$) into a latch for halt state decoding.

COMMAND ENABLE

The Command Enable (CEN) input acts as a command qualifier for the 8288. If the CEN pin is high the 8288 functions normally. If the CEN pin is pulled LOW, all command lines are held in their inactive state (not 3-state). This feature can be used to implement memory partitioning and to eliminate address conflicts between system bus devices and resident bus devices.

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
All Output and Supply Voltages ..... −0.5V to +7V
All Input Voltages ..... −1.0V to +5.5V
Power Dissipation ..... 1.5 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (V_{CC} = 5V ± 10%, T_A = 0°C to 70°C)

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_C	Input Clamp Voltage		−1	V	I_C = −5 mA
I_{CC}	Power Supply Current		230	mA	
I_F	Forward Input Current		−0.7	mA	V_F = 0.45V
I_R	Reverse Input Current		50	μA	V_R = V_{CC}
V_{OL}	Output Low Voltage				
	Command Outputs		0.5	V	I_{OL} = 32 mA
	Control Outputs		0.5	V	I_{OL} = 16 mA
V_{OH}	Output High Voltage				
	Command Outputs	2.4		V	I_{OH} = −5 mA
	Control Outputs	2.4		V	I_{OH} = −1 mA
V_{IL}	Input Low Voltage		0.8	V	
V_{IH}	Input High Voltage	2.0		V	
I_{OFF}	Output Off Current		100	μA	V_{OFF} = 0.4 to 5.25V

A.C. CHARACTERISTICS (V_{CC} = 5V ± 10%, T_A = 0°C to 70°C)*

TIMING REQUIREMENTS

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
TCLCL	CLK Cycle Period	100		ns	
TCLCH	CLK Low Time	50		ns	
TCHCL	CLK High Time	30		ns	
TSVCH	Status Active Setup Time	35		ns	
TCHSV	Status Inactive Hold Time	10		ns	
TSHCL	Status Inactive Setup Time	35		ns	
TCLSH	Status Active Hold Time	10		ns	

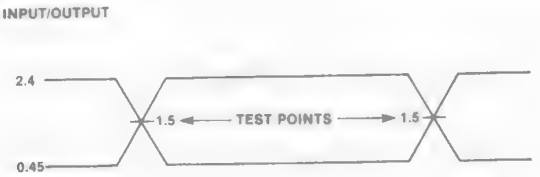
* Note: For Extended Temperature EXPRESS the Preliminary Values are TCLCL = 125; TCLCH = 50; TCHCL = 30; TCVNX = 50; TCLLH, TCLMCH = 25; TSVLH, TSVMCH = 25.

A.C. CHARACTERISTICS (Continued)

TIMING RESPONSES

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
TCVNV	Control Active Delay	5	45	ns	
TCVNX	Control Inactive Delay	10	45	ns	
TCLLH, TCLMCH	ALE MCE Active Delay (from CLK)		20	ns	
TSVLH, TSVMCH	ALE MCE Active Delay (from Status)		20	ns	
TCHLL	ALE Inactive Delay	[illegible]	15	ns	$\overline{MRDC}$, $\overline{IORC}$, $\overline{MWTC}$, $\overline{IOWC}$, $\overline{INTA}$, $\overline{AMWC}$, $\overline{AIOWC}$: I_{OL} = 32 mA, I_{OH} = −5 mA, C_L = 300 pF
TCLML	Command Active Delay	10	35	ns	
TCLMH	Command Inactive Delay	10	35	[illegible]	
TCHDTL	Direction Control Active Delay		50	ns	
TCHDTH	Direction Control Inactive Delay		30	ns	
TAELCH	Command Enable Time		40	ns	
TAEHCZ	Command Disable Time		40	[illegible]	
TAELCV	Enable Delay Time	115	200	ns	Other: I_{OL} = 16 mA, I_{OH} = −1 mA, C_L = 80 pF
TAEVNV	AEN to DEN		20	[illegible]	
TCEVNV	CEN to DEN, PDEN		25	ns	
TCELRH	CEN to Command		TCLML	ns	
TOLOH	Output, Rise Time		20	ns	From 0.8V to 2.0V
TOHOL	Output, Fall Time		12	[illegible]	From 2.0V to 0.8V

A.C. TESTING INPUT, OUTPUT WAVEFORM

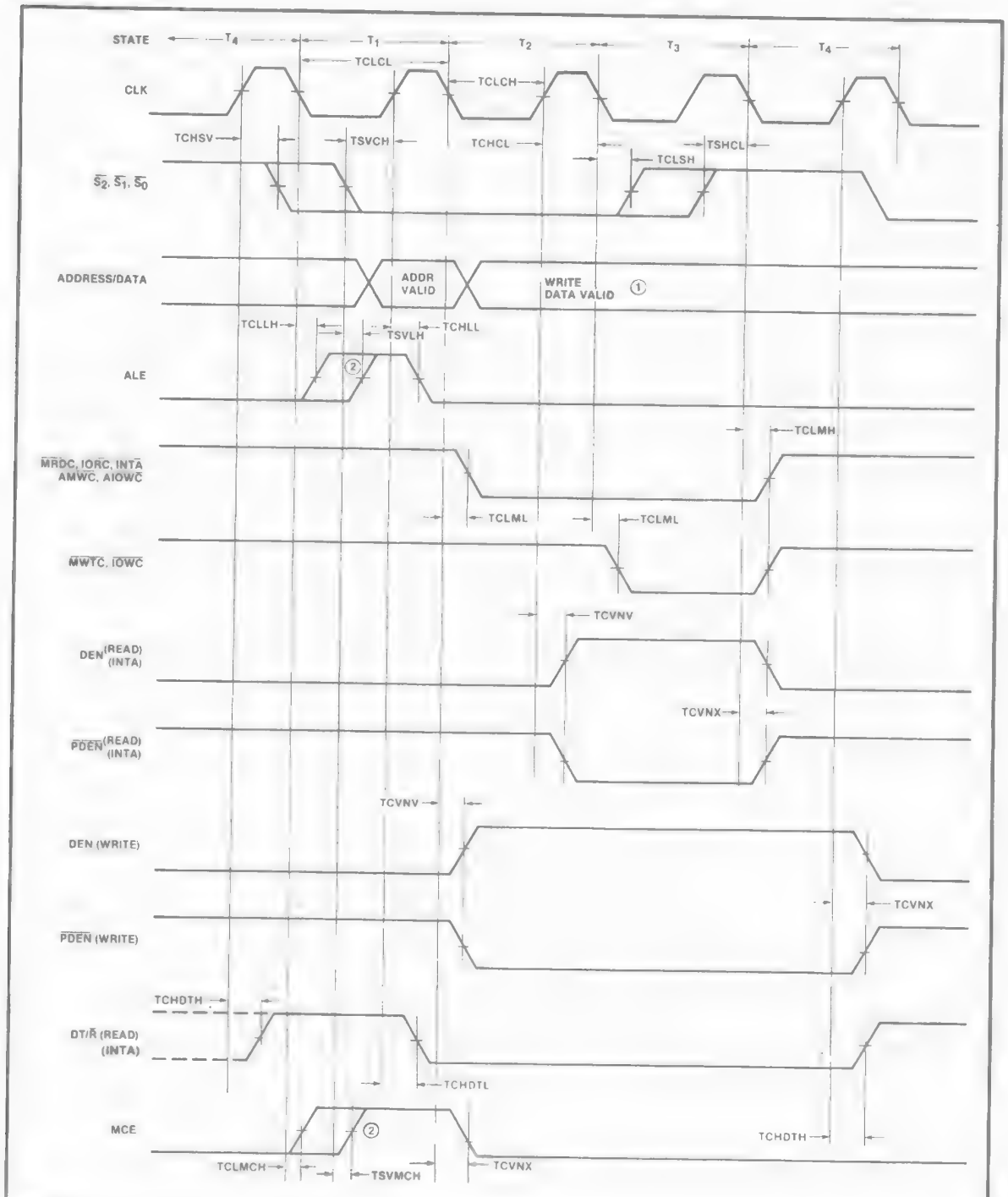


A.C. TESTING: INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0." THE CLOCK IS DRIVEN AT 4.3V AND 0.25V. TIMING MEASUREMENTS ARE MADE AT 1.5V FOR BOTH A LOGIC "1" AND "0." INPUT RISE AND FALL TIMES ARE 5 ± 2 NS., MEASURED BETWEEN 0.8V AND 2.0V

TEST LOAD CIRCUITS—3-STATE COMMAND OUTPUT TEST LOAD

AFN-01504C

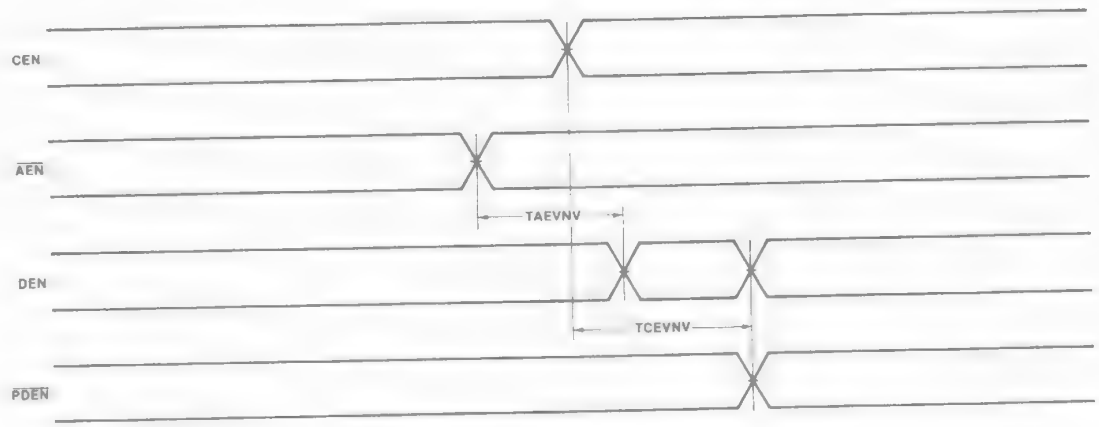
WAVEFORMS



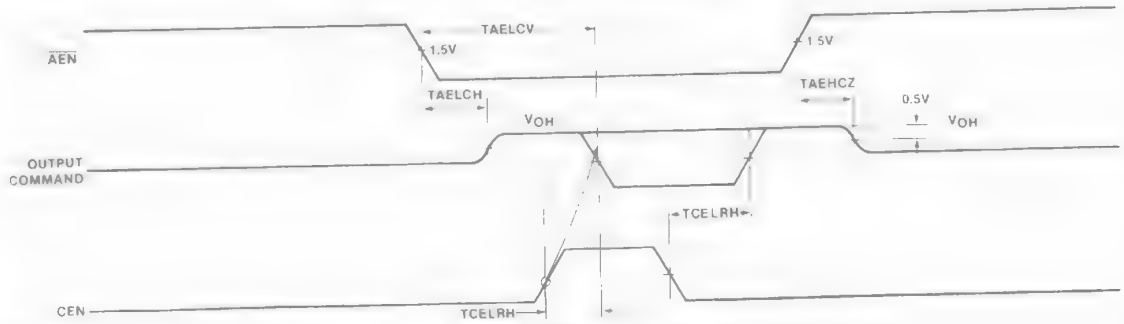
NOTES:
1. ADDRESS/DATA BUS IS SHOWN ONLY FOR REFERENCE PURPOSES
2. LEADING EDGE OF ALE AND MCE IS DETERMINED BY THE FALLING EDGE OF CLK OR STATUS GOING ACTIVE, WHICHEVER OCCURS LAST
3. ALL TIMING MEASUREMENTS ARE MADE AT 1.5V UNLESS SPECIFIED OTHERWISE

WAVEFORMS (Continued)

DEN, PDEN QUALIFICATION TIMING



ADDRESS ENABLE (AEN) TIMING (3-STATE ENABLE/DISABLE)



NOTE: CEN must be low or valid prior to T2 to prevent the command from being generated.

PRELIMINARY

8289
BUS ARBITER

- **Provides Multi-Master System Bus Protocol**
- **Synchronizes iAPX 86, 88 Processors with Multi-Master Bus**
- **Provides Simple Interface with 8288 Bus Controller**
- **Four Operating Modes for Flexible System Configuration**
- **Compatible with Intel Bus Standard MULTIBUS™**
- **Provides System Bus Arbitration for 8089 IOP in Remote Mode**
- **Available in EXPRESS**
  - **Standard Temperature Range**
  - **Extended Temperature Range**

The Intel 8289 Bus Arbiter is a 20-pin, 5-volt-only bipolar component for use with medium to large iAPX 86, 88 multi-master/multiprocessing systems. The 8289 provides system bus arbitration for systems with multiple bus masters, such as an 8086 CPU with 8089 IOP in its REMOTE mode, while providing bipolar buffering and drive capability.

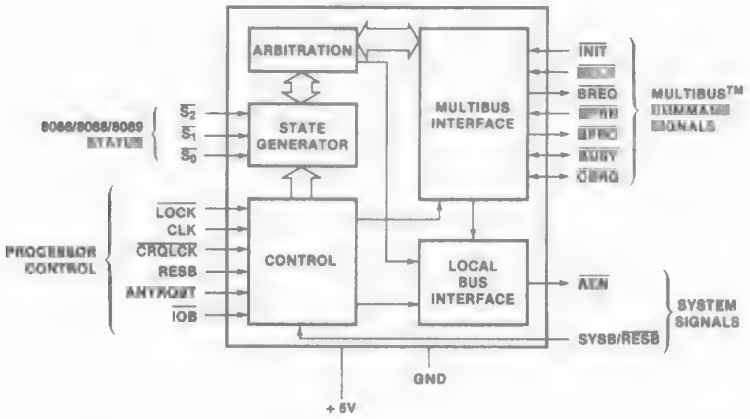


Figure 1. Block Diagram

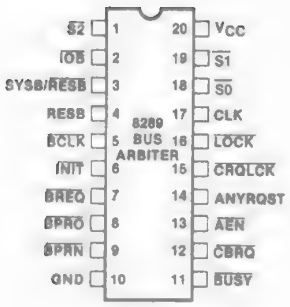


Figure 2. Pin Diagram

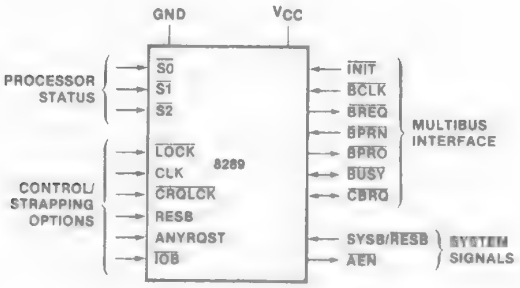


Figure 3. Functional Pinout

Table 1. Pin Description

Symbol	Type	Name and Function
V_{CC}		**Power:** +5V supply ±10%.
GND		**Ground.**
$\overline{S0}$,$\overline{S1}$,$\overline{S2}$	I	**Status Input Pins:** The status input pins from an 8086, 8088 or 8089 processor. The 8289 decodes these pins to initiate bus request and surrender actions. (See Table 2.)
CLK	I	**Clock:** From the 8284 clock chip and serves to establish when bus arbiter actions are initiated.
$\overline{LOCK}$	I	**Lock:** A processor generated signal which when activated (low) prevents the arbiter from surrendering the multi-master system bus to any other bus artiter, regardless of its priority.
$\overline{CRQLCK}$	I	**Common Request Lock:** An active low signal which prevents the arbiter from surrendering the multi-master system bus to any other bus arbiter requesting the bus through the $\overline{CBRQ}$ input pin.
RESB	I	**Resident Bus:** A strapping option to configure the arbiter to operate in systems having both a multi-master system bus and a Resident Bus. Strapped high, the multi-master system bus is requested or surrendered as a function of the SYSB/$\overline{RESB}$ input pin. Strapped low, the SYSB/$\overline{RESB}$ input is ignored.
ANYRQST	I	**Any Request:** A strapping option which permits the multi-master system bus to be surrendered to a lower priority arbiter as if it were an arbiter of higher priority (i.e., when a lower priority arbiter requests the use of the multi-master system bus, the bus is surrendered as soon as it is possible). When ANYRQST is strapped low, the bus is surrendered according to Table 2. If ANYRQST is strapped high and $\overline{CBRQ}$ is activated, the bus is surrendered at the end of the present bus cycle. Strapping $\overline{CBRQ}$ low and ANYRQST high forces the 8289 arbiter to surrender the multi-master system bus after each transfer cycle. Note that when surrender occurs BREQ is driven false (high).
$\overline{IOB}$	I	**IO Bus:** A strapping option which configures the 8289 Arbiter to operate in systems having both an IO Bus (Peripheral Bus) and a multi-master system bus. The arbiter requests and surrenders the use of the multi-master system bus as a function of the status line, $\overline{S2}$. The multi-master system bus is permitted to be surrendered while the processor is performing IO commands and is requested whenever the processor performs a memory command. Interrupt cycles are assumed as coming from the peripheral bus and are treated as an IO command.
$\overline{AEN}$	O	**Address Enable:** The output of the 8289 Arbiter to the processor's address latches, to the 8288 Bus Controller and 8284A Clock Generator. $\overline{AEN}$ serves to instruct the Bus Controller and address latches when to tri-state their output drivers.
SYSB/ $\overline{RESB}$	I	**System Bus/Resident Bus:** An input signal when the arbiter is configured in the S.R. Mode (RESB is strapped high) which determines when the multi-master system bus is requested and multi-master system bus surrendering is permitted. The signal is intended to originate from a form of address-mapping circuitry, as a decoder or PROM attached to the resident address bus. Signal transitions and glitches are permitted on this pin from ϕ1 of T4 to ϕ1 of T2 of the processor cycle. During the period from ϕ1 of T2 to ϕ1 of T4, only clean transitions are permitted on this pin (no glitches). If a glitch occurs, the arbiter may capture or miss it, and the multi-master system bus may be requested or surrendered, depending upon the state of the glitch. The arbiter requests the multi-master system bus in the S.R. Mode when the state of the SYSB/$\overline{RESB}$ pin is high and permits the bus to be surrendered when this pin is low.
$\overline{CBRQ}$	I/O	**Common Bus Request:** An input signal which instructs the arbiter if there are any other arbiters of lower priority requesting the use of the multi-master system bus. The $\overline{CBRQ}$ pins (open-collector output) of all the 8289 Bus Arbiters which surrender to the multi-master system bus upon request are connected together. The Bus Arbiter running the current transfer cycle will not itself pull the $\overline{CBRQ}$ line low. Any other arbiter connected to the $\overline{CBRQ}$ line can request the multi-master system bus. The arbiter presently running the current transfer cycle drops its $\overline{BREQ}$ signal and surrenders the bus whenever the proper surrender conditions exist. Strapping $\overline{CBRQ}$ low and ANYRQST high allows the multi-master system bus to be surrendered after each transfer cycle. See the pin definition of ANYRQST.
$\overline{INIT}$	I	**Initialize:** An active low multi-master system bus input signal used to reset all the bus arbiters on the multi-master system bus. After initialization, no arbiters have the use of the multi-master system bus.

Table 1. Pin Descriptions (Continued)

Symbol	Type	Name and Function
$\overline{BCLK}$	I	**Bus Clock:** The multi-master system bus clock to which all multi-master system bus interface signals are synchronized.
$\overline{BREQ}$	O	**Bus Request:** An active low output signal in the parallel Priority Resolving Scheme which the arbiter activates to request the use of the multi-master system bus.
$\overline{BPRN}$	I	**Bus Priority In:** The active low signal returned to the arbiter to instruct it that it may acquire the multi-master system bus on the next falling edge of BCLK. $\overline{BPRN}$ indicates to the arbiter that it is the highest priority requesting arbiter presently on the bus. The loss of $\overline{BPRN}$ instructs the arbiter that it has lost priority to a higher priority arbiter.

Symbol	Type	Name and Function
$\overline{BPRO}$	O	**Bus Priority Out:** An active low output signal used in the serial priority resolving scheme where $\overline{BPRO}$ is daisy-chained to $\overline{BPRN}$ of the next lower priority arbiter.
$\overline{BUSY}$	I/O	**Busy:** An active low open collector multi-master system bus interface signal used to instruct all the arbiters on the bus when the multi-master system bus is available. When the multi-master system bus is available the highest requesting arbiter (determined by $\overline{BPRN}$) seizes the bus and pulls $\overline{BUSY}$ low to keep other arbiters off of the bus. When the arbiter is done with the bus, it releases the $\overline{BUSY}$ signal, permitting it to go high and thereby allowing another arbiter to acquire the multi-master system bus.

FUNCTIONAL DESCRIPTION

The 8289 Bus Arbiter operates in conjunction with the 8288 Bus Controller to interface iAPX 86, 88 processors to a multi-master system bus (both the iAPX 86 and iAPX 88 are configured in their max mode). The processor is unaware of the arbiter's existence and issues commands as though it has exclusive use of the system bus. If the processor does not have the use of the multi-master system bus, the arbiter prevents the Bus Controller (8288), the data transceivers and the address latches from accessing the system bus (e.g. all bus driver outputs are forced into the high impedance state). Since the command sequence was not issued by the 8288, the system bus will appear as "Not Ready" and the processor will enter wait states. The processor will remain in Wait until the Bus Arbiter acquires the use of the multi-master system bus whereupon the arbiter will allow the bus controller, the data transceivers, and the address latches to access the system. Typically, once the command has been issued and a data transfer has taken place, a transfer acknowledge (XACK) is returned to the processor to indicate "READY" from the accessed slave device. The processor then completes its transfer cycle. Thus the arbiter serves to multiplex a processor (or bus master) onto a multi-master system bus and avoid contention problems between bus masters.

Arbitration Between Bus Masters

In general, higher priority masters obtain the bus when a lower priority master completes its present transfer cycle. Lower priority bus masters obtain the bus when a higher priority master is not accessing the system bus. A strapping option (ANYRQST) is provided to allow the arbiter to surrender the bus to a lower priority master as though it were a master of higher priority. If there are no other bus masters requesting the bus, the arbiter maintains the bus so long as its processor has not entered the HALT State. The arbiter will not voluntarily surrender the system bus and has to be forced off by another master's bus request, the HALT State being the only exception. Additional strapping options permit other modes of operation wherein the multi-master system bus is surrendered or requested under different sets of conditions.

Priority Resolving Techniques

Since there can be many bus masters on a multi-master system bus, some means of resolving priority between bus masters simultaneously requesting the bus must be provided. The 8289 Bus Arbiter provides several resolving techniques. All the techniques are based on a priority concept that at a given time one bus master will have priority above all the rest. There are provisions for using parallel priority resolving techniques, serial priority resolving techniques, and rotating priority techniques.

PARALLEL PRIORITY RESOLVING

The parallel priority resolving technique uses a separate bus request line ($\overline{BREQ}$) for each arbiter on the multi-master system bus, see Figure 4. Each $\overline{BREQ}$ line enters into a priority encoder which generates the binary address of the highest priority $\overline{BREQ}$ line which is active. The binary address is decoded by a decoder to select the corresponding $\overline{BPRN}$ (Bus Priority In) line to be returned to the highest priority requesting arbiter. The arbiter receiving priority ($\overline{BPRN}$ true) then allows its associated bus master onto the multi-master system bus as soon as it becomes available (i.e., the bus is no longer busy). When one bus arbiter gains priority over another arbiter it cannot immediately seize the bus, it must wait until the present bus transaction is complete.

Upon completing its transaction the present bus occupant recognizes that it no longer has priority and surrenders the bus by releasing $\overline{BUSY}$. $\overline{BUSY}$ is an active low "OR" tied signal line which goes to every bus arbiter on the system bus. When $\overline{BUSY}$ goes inactive (high), the arbiter which presently has bus priority ($\overline{BPRN}$ true) then seizes the bus and pulls $\overline{BUSY}$ low to keep other arbiters off of the bus. See waveform timing diagram, Figure 5. Note that all multi-master system bus transactions are synchronized to the bus clock (BCLK). This allows the parallel priority resolving circuitry or any other priority resolving scheme employed to settle.

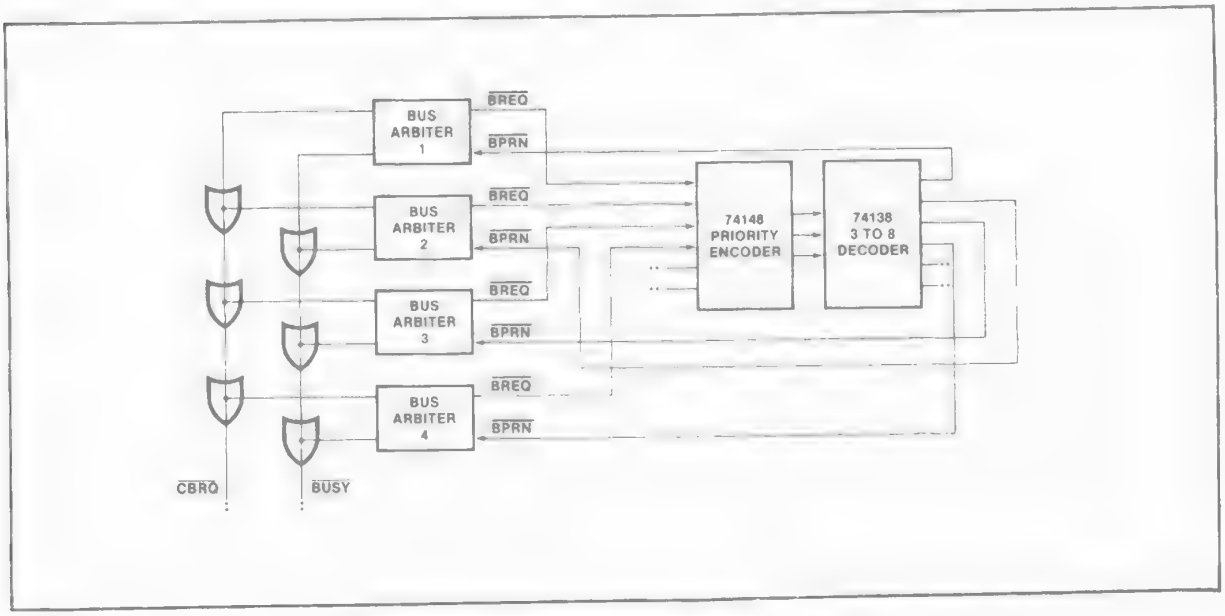


Figure 4. Parallel Priority Resolving Technique

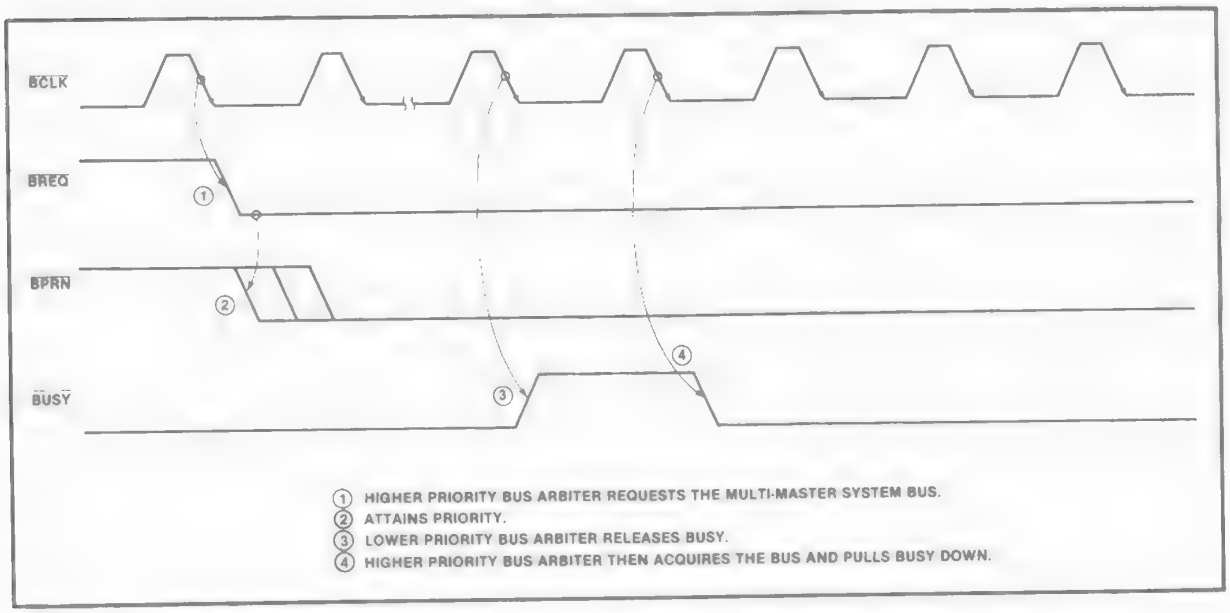
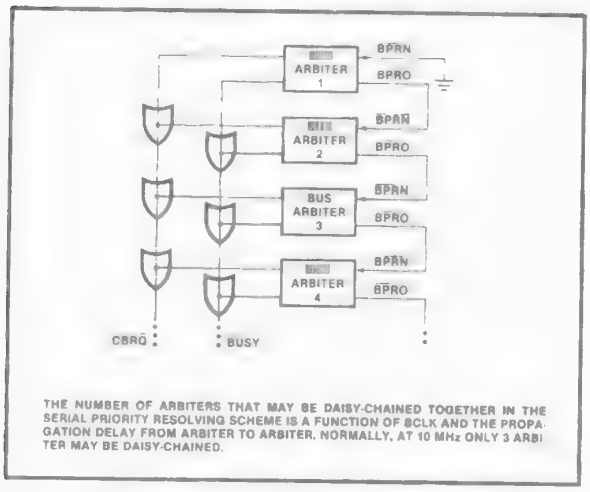


Figure 5. Higher Priority Arbiter obtaining the Bus from a Lower Priority Arbiter

SERIAL PRIORITY RESOLVING

The serial priority resolving technique eliminates the need for the priority encoder-decoder arrangement by daisy-chaining the bus arbiters together, connecting the higher priority bus arbiter's $\overline{BPRO}$ (Bus Priority Out) output to the $\overline{BPRN}$ of the next lower priority. See Figure 6.



THE NUMBER OF ARBITERS THAT MAY BE DAISY-CHAINED TOGETHER IN THE SERIAL PRIORITY RESOLVING SCHEME IS A FUNCTION OF BCLK AND THE PROPAGATION DELAY FROM ARBITER TO ARBITER. NORMALLY, AT 10 MHz ONLY 3 ARBITER MAY BE DAISY-CHAINED.

Figure 6. Serial Priority Resolving

ROTATING PRIORITY RESOLVING

The rotating priority resolving technique is similar to that of the parallel priority resolving technique except that priority is dynamically re-assigned. The priority encoder is replaced by a more complex circuit which rotates priority between requesting arbiters thus allowing each arbiter an equal chance to use the multi-master system bus, over time.

Which Priority Resolving Technique To Use

There are advantages and disadvantages for each of the techniques described above. The rotating priority resolving technique requires substantial external logic to implement while the serial technique uses no external logic but can accommodate only a limited number of bus arbiters before the daisy-chain propagation delay exceeds the multi-master's system bus clock ($\overline{BCLK}$). The parallel priority resolving technique is in general a good compromise between the other two techniques. It allows for many arbiters to be present on the bus while not requiring too much logic to implement.

8289 MODES OF OPERATION

There are two types of processors in the iAPX 86 family. An Input/Output processor (the 8089 IOP) and the iAPX 86/10, 88/10 CPUs. Consequently, there are two basic operating modes in the 8289 bus arbiter. One, the IOB (I/O Peripheral Bus) mode, permits the processor access to both an I/O Peripheral Bus and a multi-master system bus. The second, the RESB (Resident Bus mode), permits the processor to communicate over both a Resident Bus and a multi-master system bus. An I/O Peripheral Bus is a bus where all devices on that bus, including memory, are treated as I/O devices and are addressed by I/O commands. All memory commands are directed to another bus, the multi-master system bus. A Resident Bus can issue both memory and I/O commands, but it is a distinct and separate bus from the multi-master system bus. The distinction is that the Resident Bus has only one master, providing full availability and being dedicated to that one master.

The $\overline{IOB}$ strapping option configures the 8289 Bus Arbiter into the $\overline{IOB}$ mode and the strapping option RESB configures it into the RESB mode. It might be noted at this point that if both strapping options are strapped false, the arbiter interfaces the processor to a multi-master system bus only (see Figure 7). With both options strapped true, the arbiter interfaces the processor to a multi-master system bus, a Resident Bus, and an I/O Bus.

In the $\overline{IOB}$ mode, the processor communicates and controls a host of peripherals over the Peripheral Bus. When the I/O Processor needs to communicate with system memory, it does so over the system memory bus. Figure 8 shows a possible I/O Processor system configuration.

The iAPX 86 and iAPX 88 processors can communicate with a Resident Bus and a multi-master system bus. Two bus controllers and only one Bus Arbiter would be needed in such a configuration as shown in Figure 9. In such a system configuration the processor would have access to memory and peripherals of both busses. Memory mapping techniques are applied to select which bus is to be accessed. The SYSB/RESB input on the arbiter serves to instruct the arbiter as to whether or not the system bus is to be accessed. The signal connected to SYSB/RESB also enables or disables commands from one of the bus controllers.

A summary of the modes that the 8289 has, along with its response to its status lines inputs, is summarized in Table 2.

*In some system configurations it is possible for a non-I/O Processor to have access to more than one Multi-Master System Bus, see 8289 Application Note.

Table 2. Summary of 8289 Modes, Requesting and Relinquishing the Multi-Master System Bus

	Status Lines From 8086 or 8088 or 8089			IOB Mode Only	RESB (Mode) Only IOB = High RESB = High		IOB Mode RESB Mode IOB = Low RESB = High		Single Bus Mode IOB = High RESB = Low
	$\overline{S2}$	$\overline{S1}$	$\overline{S0}$	$\overline{IOB}$ = Low	SYSB/RESB = High	SYSB/$\overline{RESB}$ = Low	SYSB/$\overline{RESB}$ = High	SYSB/$\overline{RESB}$ = Low	
I/O COMMANDS	0	0	0	x		x	x	x	
	0	0	1	x		x	x	x	
	0	1	0	x		x	x	x	
HALT	0	1	1	x	x	x	x	x	x
MEM COMMANDS	1	0	0			x		x	
	1	0	1			x		x	
	1	1	0			x		x	
IDLE	1	1	1	x	x	x	x	x	x

NOTES:
1. X = Multi-Master System Bus is allowed to be Surrendered.
2. ✓ = Multi-Master System Bus is Requested.

Mode	Pin Strapping	Multi-Master System Bus Requested**	Multi-Master System Bus Surrendered*
Single Bus Multi-Master Mode	$\overline{IOB}$ = High RESB = Low	Whenever the processor's status lines go active	HLT + TI • CBRQ + HPBRQ†
RESB Mode Only	$\overline{IOB}$ = High RESB = High	SYSB/$\overline{RESB}$ = High • ACTIVE STATUS	(SYSB/$\overline{RESB}$ = Low + TI) • CBRQ + HLT + HPBRQ
IOB Mode Only	$\overline{IOB}$ = Low RESB = Low	Memory Commands	(I/O Status + TI) • CBRQ + HLT + HPBRQ
IOB Mode RESB Mode	$\overline{IOB}$ = Low RESB = High	(Memory Command) • (SYSB/$\overline{RESB}$ = High)	((I/O Status Commands) + SYSB/$\overline{RESB}$ = LOW)) • CBRQ + HPBRQ† + HLT

NOTES:
*$\overline{LOCK}$ prevents surrender of Bus to any other arbiter, $\overline{CRQLCK}$ prevents surrender of Bus to any lower priority arbiter.
**Except for HALT and Passive or IDLE Status.
†HPBRQ, Higher priority Bus request or $\overline{BPRN}$ = 1.
1. $\overline{IOB}$ Active Low.
2. RESB Active High.
3. + is read as "OR" and • as "AND."
4. TI = Processor Idle Status $\overline{S2}$, $\overline{S1}$, $\overline{S0}$ = 111
5. HLT = Processor Halt Status $\overline{S2}$, $\overline{S1}$, $\overline{S0}$ = 011

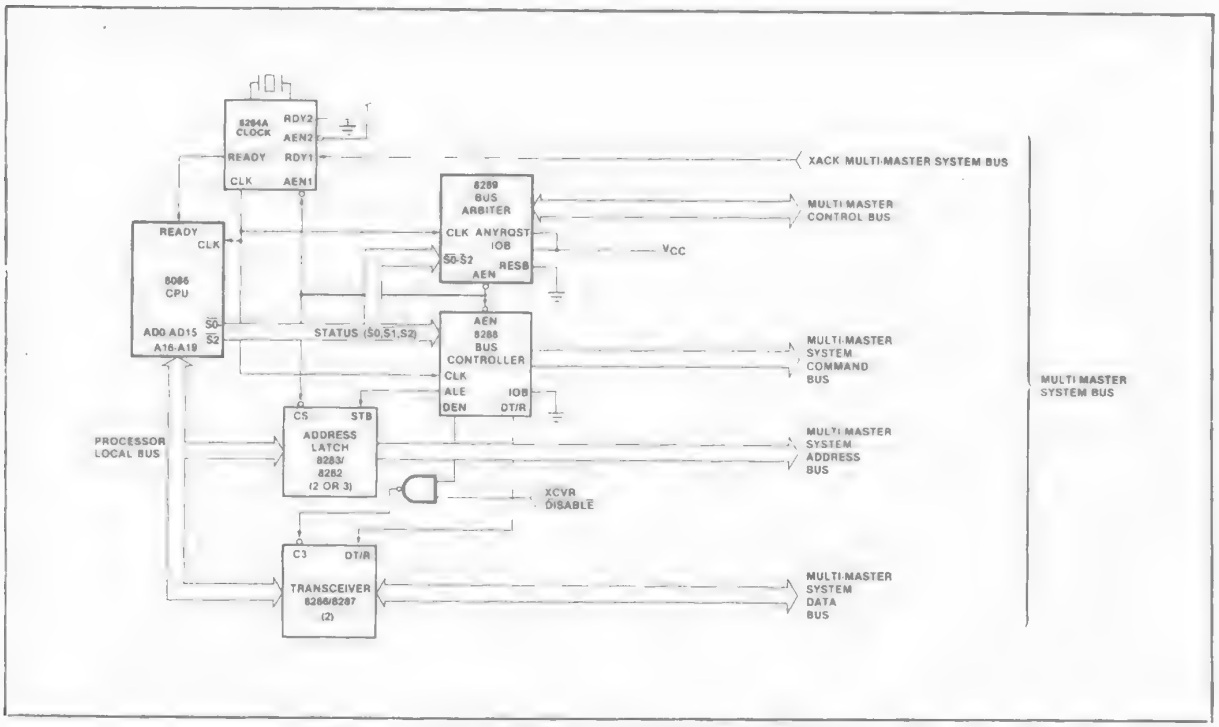


Figure 7. Typical Medium Complexity CPU System

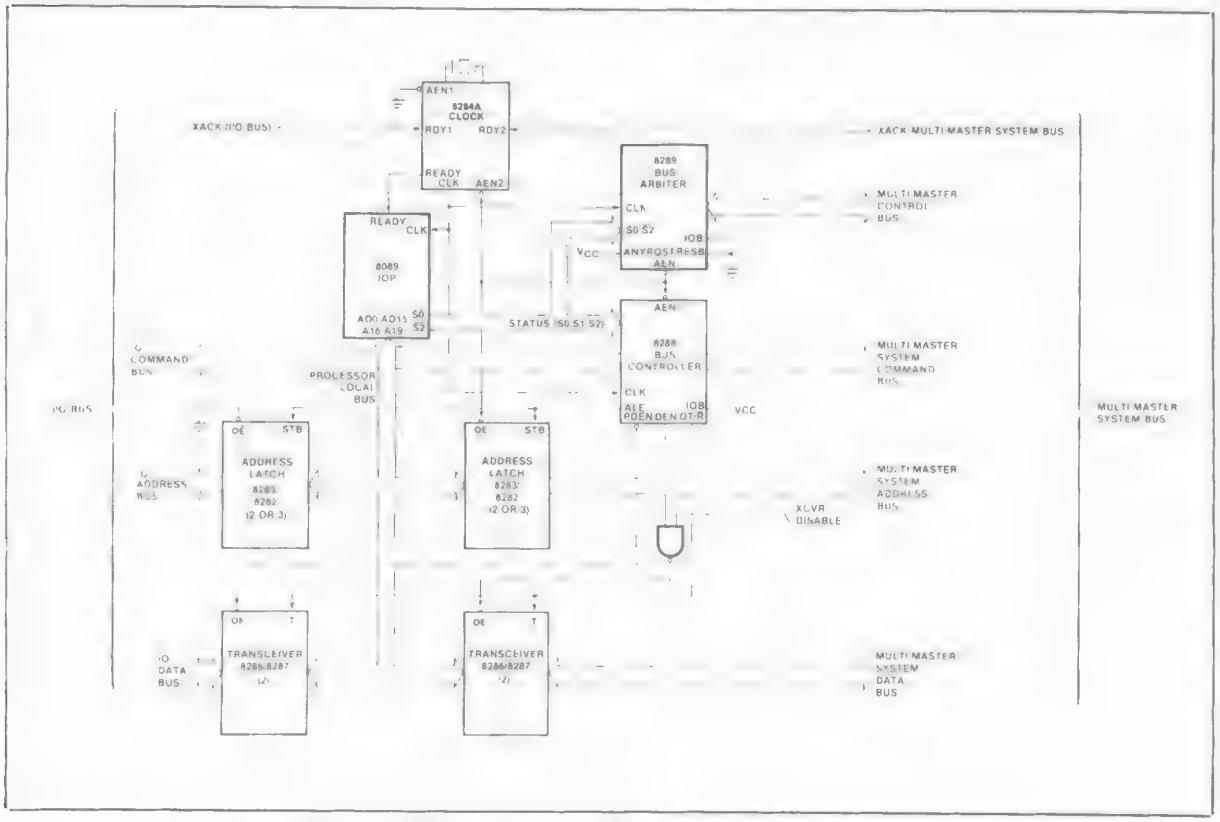


Figure 8. Typical Medium Complexity IOB System

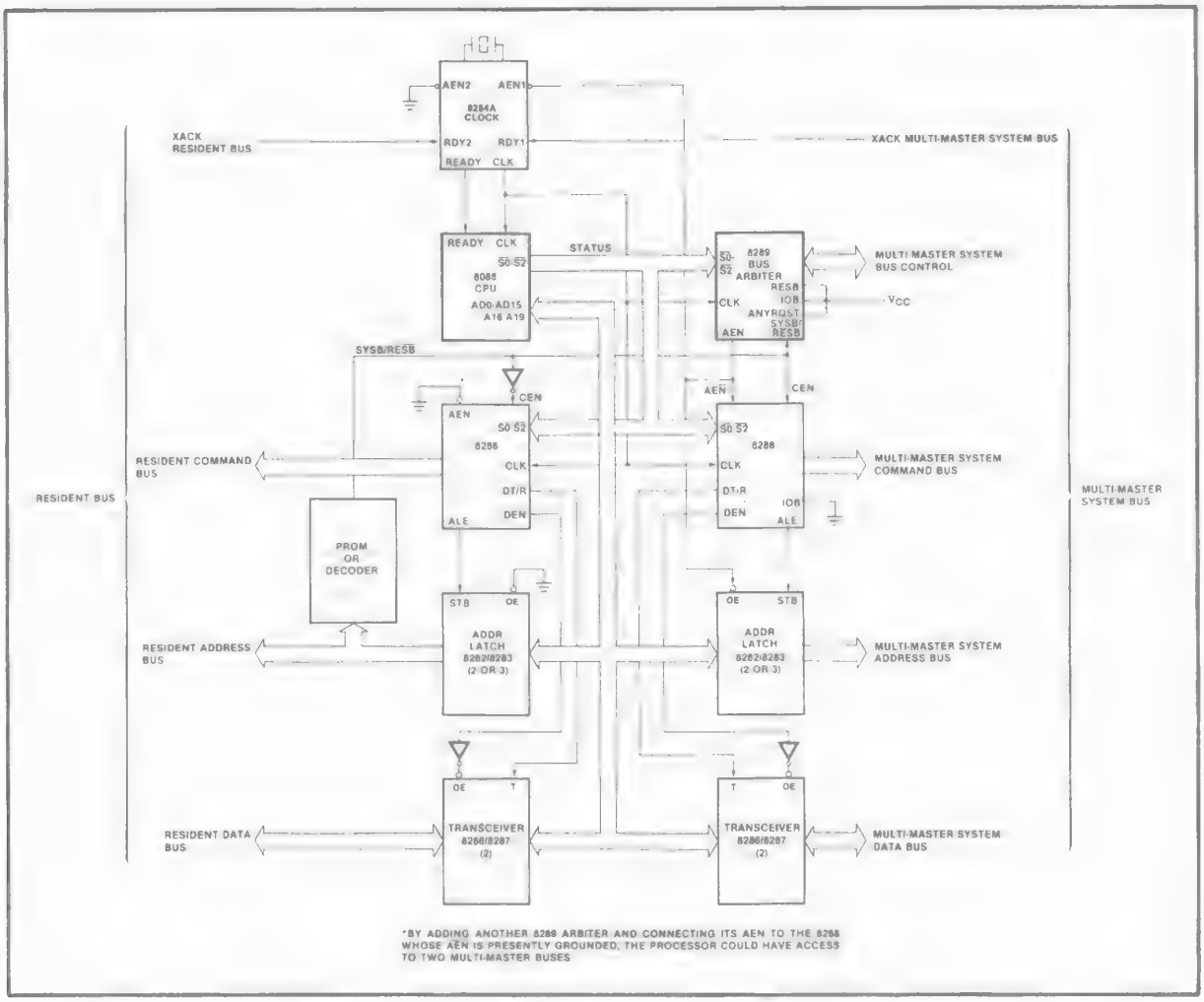


Figure 9. 8289 Bus Arbiter Shown in System-Resident Bus Configuration

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias . . . . . 0°C to 70°C
Storage Temperature . . . . . – 65°C to + 150°C
All Output and Supply Voltages . . . . . – 0.5V to + 7V
All Input Voltages . . . . . – 1.0V to + 5.5V
Power Dissipation . . . . . 1.5 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = +5V ±10%)

Symbol	Parameter	Min.	Max.	Units	Test Condition
V_C	Input Clamp Voltage		– 1.0	V	V_{CC} = 4.50V, I_C = – 5 mA
I_F	Input Forward Current		– 0.5	mA	V_{CC} = 5.50V, V_F = 0.45V
I_R	Reverse Input Leakage Current		60	μA	V_{CC} = 5.50, V_R = 5.50
V_{OL}	Output Low Voltage $\overline{BUSY}$, $\overline{CBRQ}$ $\overline{AEN}$ $\overline{BPRO}$, $\overline{BREQ}$		 0.45 0.45 0.45	 V V V	 I_{OL} = 20 mA I_{OL} = 16 mA I_{OL} = 10 mA
V_{OH}	Output High Voltage $\overline{BUSY}$, $\overline{CBRQ}$	Open Collector			
	All Other Outputs	2.4		V	I_{OH} = 400 μA
I_{CC}	Power Supply Current		165	mA	
V_{IL}	Input Low Voltage		.8	V	
V_{IH}	Input High Voltage	2.0		V	
Cin Status	Input Capacitance		25	pF	
Cin (Others)	Input Capacitance		12	pF	

A.C. CHARACTERISTICS (V_{CC} = +5V ±10%, T_A = 0°C to 70°C)

TIMING REQUIREMENTS

Symbol	Parameter	Min.	Max.	Unit	Test Condition
TCLCL	CLK Cycle Period	125		ns	
TCLCH	CLK Low Time	65		ns	
TCHCL	CLK High Time	35		ns	
TSVCH	Status Active Setup	65	TCLCL-10	ns	
TSHCL	Status Inactive Setup	50	TCLCL-10	ns	
THVCH	Status Active Hold	10		ns	
THVCL	Status Inactive Hold	10		ns	
TBYSBL	BUSY↑↓Setup to BCLK↓	20		ns	
TCBSBL	CBRQ↑↓Setup to BCLK↓	20		ns	
TBLBL	BCLK Cycle Time	100		ns	
TBHCL	BCLK High Time	30	.65[TBLBL]	ns	
TCLLL1	LOCK Inactive Hold	10		ns	
TCLLL2	LOCK Active Setup	40		ns	
TPNBL	BPRN↓↑to BCLK Setup Time	15		ns	
TCLSR1	SYSB/RESB Setup	0		ns	
TCLSR2	SYSB/RESB Hold	20		ns	
TIVIH	Initialization Pulse Width	3 TBLBL+ 3 TCLCL		ns	

A.C. CHARACTERISTICS (Continued)

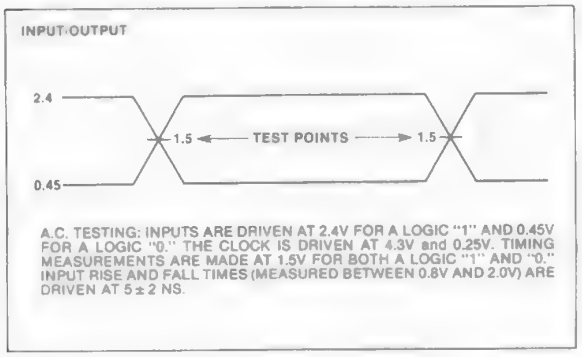
TIMING RESPONSES

Symbol	Parameter	Min.	Max.	Unit	Test Condition
TBLBRL	BCLK to BREQ Delay↓↑		35	ns	
TBLPOH	BCLK to BPRO↓↑ (See Note 1)		40	ns	
TPNPO	BPRN↓↑to BPRO↓↑Delay (See Note 1)		25	ns	
TBLBYL	BCLK to BUSY Low		60	ns	
TBLBYH	BCLK to BUSY Float (See Note 2)		35	ns	
TCLAEH	CLK to AEN High		65	ns	
TBLAEL	BCLK to AEN Low		40	ns	
TBLCBL	BCLK to CBRQ Low		60	ns	
TRLCRH	BCLK to CBRQ Float (See Note 2)		35	ns	
TOLOH	Output Rise Time		20	ns	From 0.8V to 2.0V
TOHOL	Output Fall Time		12	ns	From 2.0V to 0.8V

↓↑ Denotes that spec applies to both transitions of the signal.

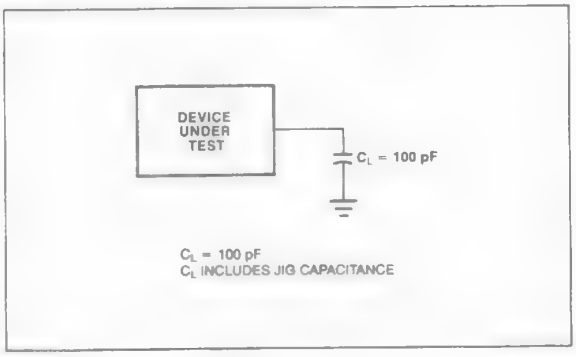
NOTES:
1. BCLK generates the first BPRO wherein subsequent BPRO changes lower in the chain are generated through BPRON.
2. Measured at .5V above GND.

A.C. TESTING INPUT, OUTPUT WAVEFORM

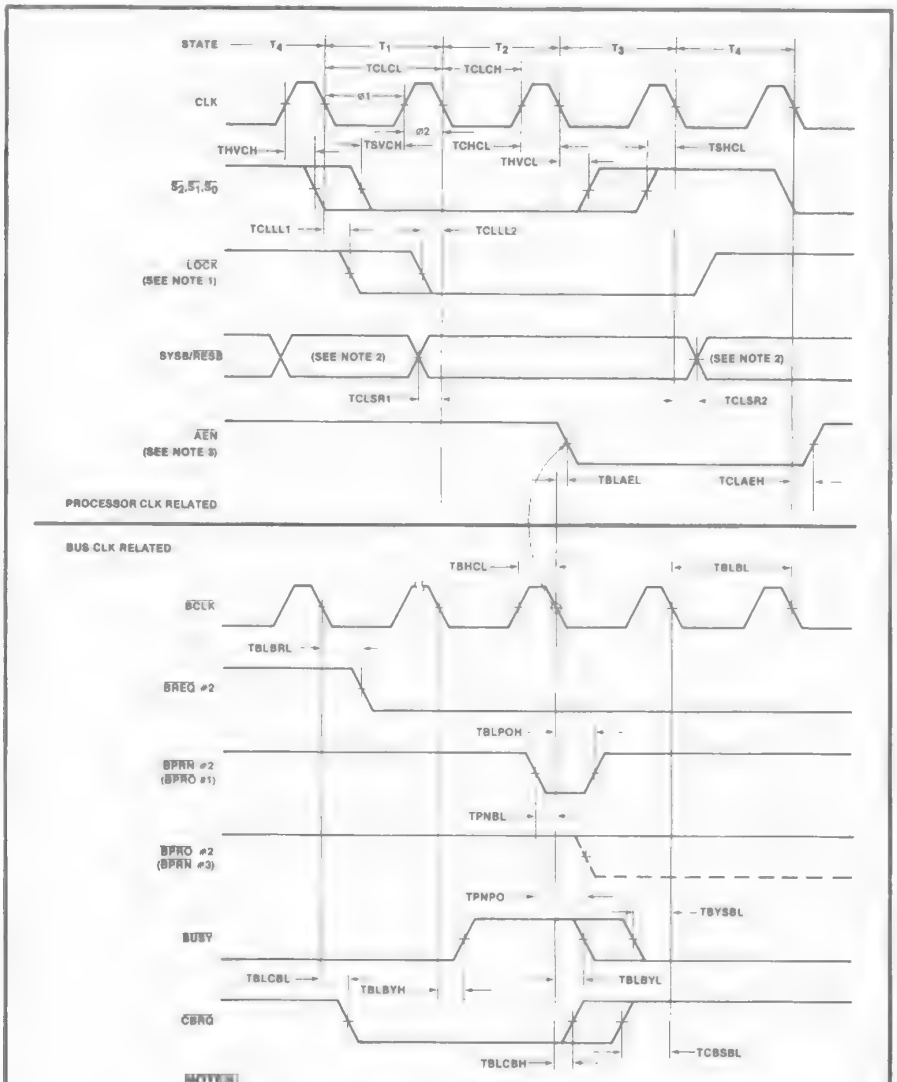


A.C. TESTING: INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0." THE CLOCK IS DRIVEN AT 4.3V and 0.25V. TIMING MEASUREMENTS ARE MADE AT 1.5V FOR BOTH A LOGIC "1" AND "0." INPUT RISE AND FALL TIMES (MEASURED BETWEEN 0.8V AND 2.0V) ARE DRIVEN AT 5 ± 2 NS.

A.C. TESTING LOAD CIRCUIT



WAVEFORMS



NOTES:

1. LOCK ACTIVE CAN OCCUR DURING ANY STATE, AS LONG AS THE RELATIONSHIPS SHOWN ABOVE WITH RESPECT TO THE CLK ARE MAINTAINED LOCK INACTIVE HAS NO CRITICAL TIME AND CAN BE ASYNCHRONOUS CRQLCK HAS NO CRITICAL TIMING AND IS CONSIDERED AN ASYNCHRONOUS INPUT SIGNAL
2. GLITCHING OF SYSB/RESB PIN IS PERMITTED DURING THIS TIME. AFTER ϕ2 OF T1, AND BEFORE ϕ1 OF T4, SYSB/RESB SHOULD BE STABLE.
3. AEN LEADING EDGE IS RELATED TO BCLK, TRAILING EDGE TO CLK. THE TRAILING EDGE OF AEN OCCURS AFTER BUS PRIORITY IS LOST.

ADDITIONAL NOTES:

The signals related to CLK are typical processor signals, and do not relate to the depicted sequence of events of the signals referenced to BCLK. The signals shown related to the BCLK represent a hypothetical sequence of events for illustration. Assume 3 bus arbiters of priorities 1, 2 and 3 configured in serial priority resolving scheme as shown in Figure 6. Assume arbiter 1 has the bus and is holding busy low. Arbiter #2 detects its processor wants the bus and pulls low BREQ#2. If BPRN#2 is high (as shown), arbiter #2 will pull low CBRQ line. CBRQ signals to the higher priority arbiter #1 that a lower priority arbiter wants the bus. [A higher priority arbiter would be granted BPRN when it makes the bus request rather than having to wait for another arbiter to release the bus through CBRQ].** Arbiter #1 will relinquish the multi-master system bus when it enters a state not requiring it (see Table 1), by lowering its BPRO#1 (tied to BPRN#2) and releasing BUSY. Arbiter #2 now sees that it has priority from BPRN#2 being low and releases CBRQ. As soon as BUSY signifies the bus is available (high), arbiter #2 pulls BUSY low on next falling edge of BCLK. Note that if arbiter #2 didn't want the bus at the time it received priority, it would pass priority to the next lower priority arbiter by lowering its BPRO #2 [TPNPO].

**Note that even a higher priority arbiter which is acquiring the bus through BPRN will momentarily drop CBRQ until it has acquired the bus

iAPX 286 Microprocessors

4

ADVANCE INFORMATION

iAPX 286/10
HIGH PERFORMANCE MICROPROCESSOR WITH MEMORY MANAGEMENT AND PROTECTION

- **High Performance 8 and 10 MHz Processor (Up to six times iAPX 86)**
- **Large Address Space:**
  - **—16 Megabytes Physical**
  - **—1 Gigabyte Virtual per Task**
- **Integrated Memory Management, Four-Level Memory Protection and Support for Virtual Memory and Operating Systems**
- **Two iAPX 86 Upward Compatible Operating Modes:**
  - **—iAPX 86 Real Address Mode**
  - **—Protected Virtual Address Mode**
- **Optional Processor Extension:**
  - **—iAPX 286/20 High Performance 80-bit Numeric Data Processor**
- **Complete System Development Support:**
  - **—Development Software: Assembler, PL/M, Pascal, FORTRAN, and System Utilities**
  - **—In-Circuit-Emulator (ICE™-286)**
- **High Bandwidth Bus Interface (8 or 10 Megabyte/Sec)**
- **Available in EXPRESS:**
  - **—Standard Temperature Range**

The iAPX 286/10 (80286 part number) is an advanced, high-performance microprocessor with specially optimized capabilities for multiple user and multi-tasking systems. The 80286 has built-in memory protection that supports operating system and task isolation as well as program and data privacy within tasks. A 10 MHz iAPX 286/10 provides up to six times greater throughput than the standard 5 MHz iAPX 86/10. The 80286 includes memory management capabilities that map up to 2^{30} bytes (one gigabyte) of virtual address space per task into 2^{24} bytes (16 megabytes) of physical memory.

The iAPX 286 is upward compatible with iAPX 86 and 88 software. Using iAPX 86 real address mode, the 80286 is object code compatible with existing iAPX 86, 88 software. In protected virtual address mode, the 80286 is source code compatible with iAPX 86, 88 software and may require upgrading to use virtual addresses supported by the 80286's integrated memory management and protection mechanism. Both modes operate at full 80286 performance and execute a superset of the iAPX 86 and 88's instructions.

The 80286 provides special operations to support the efficient implementation and execution of operating systems. For example, one instruction can end execution of one task, save its state, switch to a new task, load its state, and start execution of the new task. The 80286 also supports virtual memory systems by providing a segment-not-present exception and restartable instructions.

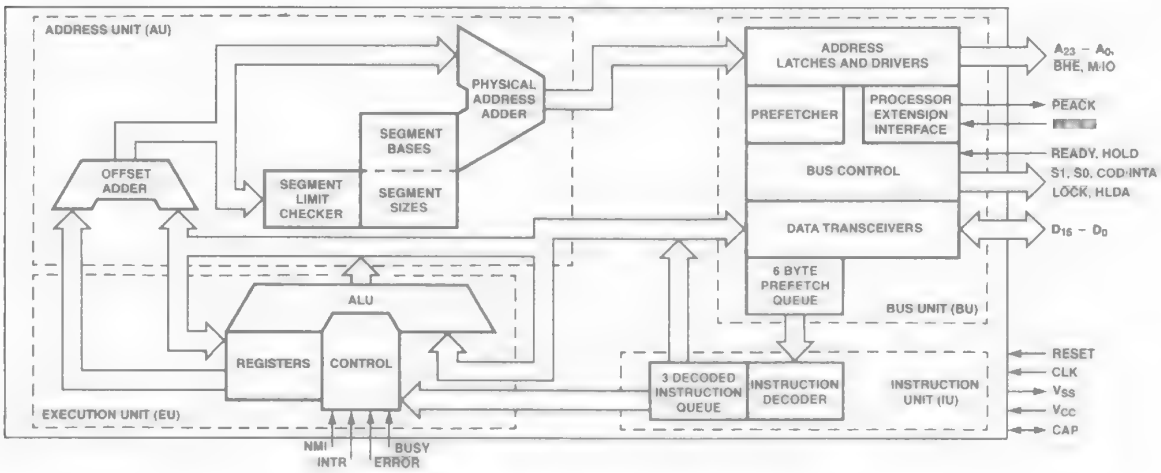


Figure 1. 80286 Internal Block Diagram

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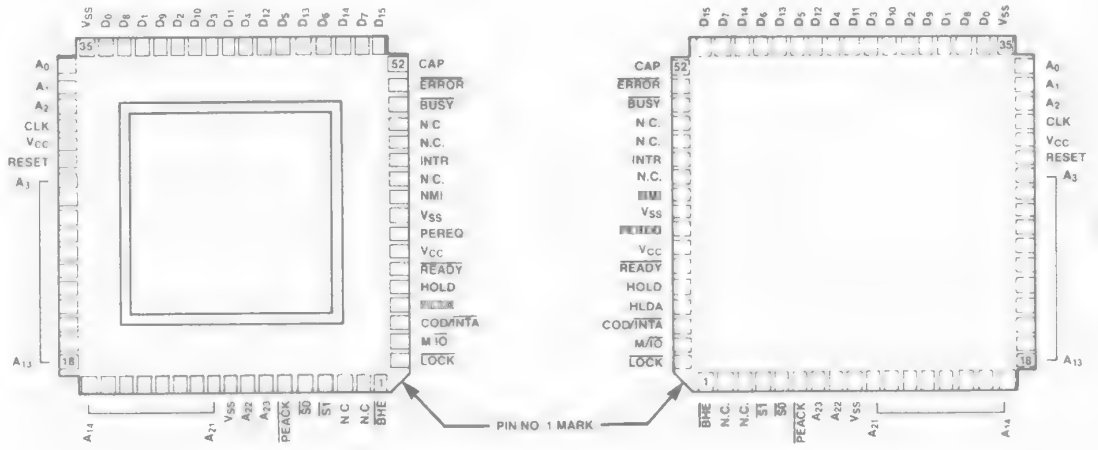
ORDER NUMBER: 210253-001

Component Pad View—As viewed from underside of component when mounted on the board.

P.C. Board View—As viewed from the component side of the P.C. board.



NOTE: N.C. pads must not be connected.

Figure 2. 80286 Pin Configuration

Table 1. Pin Description

The following pin function descriptions are for the 80286 microprocessor:

Symbol	Type	Name and Function
CLK	I	**System Clock** provides the fundamental timing for iAPX 286 systems. It is a 16 MHz signal divided by two inside the 80286 to generate the 8 MHz processor clock. The internal divide-by-two circuitry can be synchronized to an external clock generator by a LOW to HIGH transition on the RESET input.
D_{15}-D_0	I/O	**Data Bus** inputs data during memory, I/O, and interrupt acknowledge read cycles; outputs data during memory and I/O write cycles. The data bus is active HIGH and floats to 3-state OFF during bus hold acknowledge.
A_{23}-A_0	O	**Address Bus** outputs physical memory and I/O port addresses. A0 is LOW when data is to be transferred on pins D_{7-0}. A_{23}-A_{16} are LOW during I/O transfers. The address bus is active HIGH and floats to 3-state OFF during bus hold acknowledge.
$\overline{BHE}$	O	**Bus High Enable** indicates transfer of data on the upper byte of the data bus, D_{15-8}. Eight-bit oriented devices assigned to the upper byte of the data bus would normally use $\overline{BHE}$ to condition chip select functions. $\overline{BHE}$ is active LOW and floats to 3-state OFF during bus hold acknowledge.

$\overline{BHE}$ and A0 Encodings

$\overline{BHE}$ Value	A0 Value	Function
0	0	Word transfer
0	1	Byte transfer on upper half of data bus (D_{15-8})
1	0	Byte transfer on lower half of data bus (D_{7-0})
1	1	Reserved

Table 1. Pin Description (Cont.)

Symbol	Type	Name and Function
$\overline{S1}$, $\overline{S0}$	O	**Bus Cycle Status** indicates initiation of a bus cycle and, along with M/IO and COD/INTA, defines the type of bus cycle. The bus is in a T_S state whenever one or both are LOW. $\overline{S1}$ and $\overline{S0}$ are active LOW and float to 3-state OFF during bus hold acknowledge.

80286 Bus Cycle Status Definition

COD/INTA	M/$\overline{IO}$	$\overline{S1}$	$\overline{S0}$	Bus cycle initiated
0 (LOW)	0	0	0	Interrupt acknowledge
0	0	0	1	Reserved
0	0	1	0	Reserved
0	0	1	1	None; not a status cycle
0	1	0	0	IF A1 = 1 then halt; else shutdown
0	1	0	1	Memory data read
0	1	1	0	Memory data write
0	1	1	1	None; not a status cycle
1 (HIGH)	0	0	0	Reserved
1	0	0	1	I/O read
1	0	1	0	I/O write
1	0	1	1	None; not a status cycle
1	1	0	0	Reserved
1	1	0	1	Memory instruction read
1	1	1	0	Reserved
1	1	1	1	None; not a status cycle

Symbol	Type	Name and Function
M/$\overline{IO}$	O	**Memory/IO Select** distinguishes memory access from I/O access. If HIGH during T_S, a memory cycle or a halt shutdown cycle is in progress. If LOW, an I/O cycle or an interrupt acknowledge cycle is in progress. M/$\overline{IO}$ floats to 3-state OFF during bus hold acknowledge.
COD/$\overline{INTA}$	O	**Code/Interrupt Acknowledge** distinguishes instruction fetch cycles from memory data read cycles. Also distinguishes interrupt acknowledge cycles from I/O cycles. COD/$\overline{INTA}$ floats to 3-state OFF during bus hold acknowledge.
$\overline{LOCK}$	O	**Bus Lock** indicates that other system bus masters are not to gain control of the system bus following the current bus cycle. The $\overline{LOCK}$ signal may be activated explicitly by the "LOCK" instruction prefix or automatically by 80286 hardware during memory XCHG instructions, interrupt acknowledge, or descriptor table access. $\overline{LOCK}$ is active LOW and floats to 3-state OFF during bus hold acknowledge.
$\overline{READY}$	I	**Bus Ready** terminates a bus cycle. Bus cycles are extended without limit until terminated by $\overline{READY}$ LOW. $\overline{READY}$ is an active LOW synchronous input requiring setup and hold times relative to the system clock be met for correct operation. $\overline{READY}$ is ignored during bus hold acknowledge.
HOLD HLDA	I O	**Bus Hold Request and Hold Acknowledge** control ownership of the 80286 local bus. The HOLD input allows another local bus master to request control of the local bus. When control is granted, the 80286 will float its bus drivers to 3-state OFF and then activate HLDA, thus entering the bus hold acknowledge condition. The local bus will remain granted to the requesting master until HOLD becomes inactive which results in the 80286 deactivating HLDA and regaining control of the local bus. This terminates the bus hold acknowledge condition. HOLD may be asynchronous to the system clock. These signals are active HIGH.
INTR	I	**Interrupt Request** requests the 80286 to suspend its current program execution and service a pending external request. Interrupt requests are masked whenever the interrupt enable bit in the flag word is cleared. When the 80286 responds to an interrupt request, it performs two interrupt acknowledge bus cycles to read an 8-bit interrupt vector that identifies the source of the interrupt. To assure program interruption, INTR must remain active until the first interrupt acknowledge cycle is completed. INTR is sampled at the beginning of each processor cycle and must be active HIGH at least two processor cycles before the current instruction ends in order to interrupt before the next instruction. INTR is level sensitive, active HIGH, and may be asynchronous to the system clock.
NMI	I	**Non-maskable Interrupt Request** interrupts the 80286 with an internally supplied vector value of 2. No interrupt acknowledge cycles are performed. The interrupt enable bit in the 80286 flag word does not affect this input. The NMI input is active HIGH, may be asynchronous to the system clock, and is edge triggered after internal synchronization. For proper recognition, the input must have been previously LOW for at least four system clock cycles and remain HIGH for at least four system clock cycles.

Table 1. Pin Description (Cont.)

Symbol	Type	Name and Function
PEREQ PEACK	I O	**Processor Extension Operand Request and Acknowledge** extend the memory management and protection capabilities of the 80286 to processor extensions. The PEREQ input requests the 80286 to perform a data operand transfer for a processor extension. The PEACK output signals the processor extension when the requested operand is being transferred. PEREQ is active HIGH and may be asynchronous to the system clock. PEACK is active LOW.
BUSY ERROR	I I	**Processor Extension Busy and Error** indicate the operating condition of a processor extension to the 80286. An active BUSY input stops 80286 program execution on WAIT and some ESC instructions until BUSY becomes inactive (HIGH). The 80286 may be interrupted while waiting for BUSY to become inactive. An active ERROR input causes the 80286 to perform a processor extension interrupt when executing WAIT or some ESC instructions. These inputs are active LOW and may be asynchronous to the system clock.
RESET	I	**System Reset** clears the internal logic of the 80286 and is active HIGH. The 80286 may be re-initialized at any time with a LOW to HIGH transition on RESET which remains active for more than 16 system clock cycles. During RESET active, the output pins of the 80286 enter the state shown below: **80286 Pin State During Reset** Pin Value — Pin Names 1 (HIGH) — S0, S1, PEACK, A23-A0, BHE, LOCK 0 (LOW) — M/IO, COD/INTA, HLDA 3-state OFF — D_{15}–D_0 Operation of the 80286 begins after a HIGH to LOW transition on RESET. The HIGH to LOW transition of RESET must be synchronous to the system clock. Approximately 50 system clock cycles are required by the 80286 for internal initializations before the first bus cycle to fetch code from the power-on execution address is performed. A LOW to HIGH transition of RESET synchronous to the system clock, will begin a new processor cycle at the next HIGH to LOW transition of the system clock. The LOW to HIGH transition of RESET may be asynchronous to the system clock; however, in this case it can not be predetermined which phase of the processor clock will occur during the next system clock period. Synchronous LOW to HIGH transitions of RESET are only required for systems where the processor clock must be phase synchronous to another clock.
V_{SS}	I	**System Ground:** 0 VOLTS.
V_{CC}	I	**System Power:** +5 Volt Power Supply.
CAP	I	**Substrate Filter Capacitor:** a 0.047μf ± 20% 12V capacitor must be connected between this pin and ground. This capacitor filters the output of the internal substrate bias generator. A maximum DC leakage current of 1 μa is allowed through the capacitor. For correct operation of the 80286, the substrate bias generator must charge this capacitor to its operating voltage. The capacitor chargeup time is 5 milliseconds (max.) after V_{CC} and CLK reach their specified AC and DC parameters. RESET may be applied to prevent spurious activity by the CPU during this time. After this time, the 80286 processor clock can be phase synchronized to another clock by pulsing RESET LOW synchronous to the system clock.

FUNCTIONAL DESCRIPTION

Introduction

The 80286 is an advanced, high-performance microprocessor with specially optimized capabilities for multiple user and multi-tasking systems. Depending on the application, the 80286's performance is up to six times faster than the standard 5 MHz 8086's, while providing complete upward software compatibility with Intel's iAPX 86, 88, and 186 family of CPU's.

The 80286 operates in two modes: iAPX 86 real address mode and protected virtual address mode. Both modes execute a superset of the iAPX 86 and 88 instruction set.

In iAPX 86 real address mode programs use real addresses with up to one megabyte of address space. Programs use virtual addresses in protected virtual address mode, also called protected mode. In protected mode, the 80286 CPU automatically maps 1 gigabyte of virtual addresses per task into a 16 megabyte real address space. This mode also provides memory protection to isolate the operating system and ensure privacy of each tasks' programs and data. Both modes provide the same base instruction set, registers, and addressing modes.

The following Functional Description describes first, the base 80286 architecture common to both modes, second, iAPX 86 real address mode, and third, protected mode.

iAPX 286/10 BASE ARCHITECTURE

The iAPX 86, 88, 186, and 286 CPU family all contain the same basic set of registers, instructions, and addressing modes. The 80286 processor is upward compatible with the 8086, 8088, and 80186 CPU's.

Register Set

The 80286 base architecture has fifteen registers as shown in Figure 3. These registers are grouped into the following four categories:

General Registers: Eight 16-bit general purpose registers used to contain arithmetic and logical operands. Four of these (AX, BX, CX, and DX) can be used either in their entirety as 16-bit words or split into pairs of separate 8-bit registers.

Segment Registers: Four 16-bit special purpose registers select, at any given time, the segments of memory that are immediately addressable for code, stack, and data. (For usage, refer to Memory Organization.)

Base and Index Registers: Four of the general purpose registers may also be used to determine offset addresses of operands in memory. These registers may contain base addresses or indexes to particular locations within a segment. The addressing mode determines the specific registers used for operand address calculations.

Status and Control Registers: Three 16-bit special purpose registers record or control certain aspects of the 80286 processor state. These include the Instruction Pointer, which contains the offset address of the next sequential instruction to be executed.

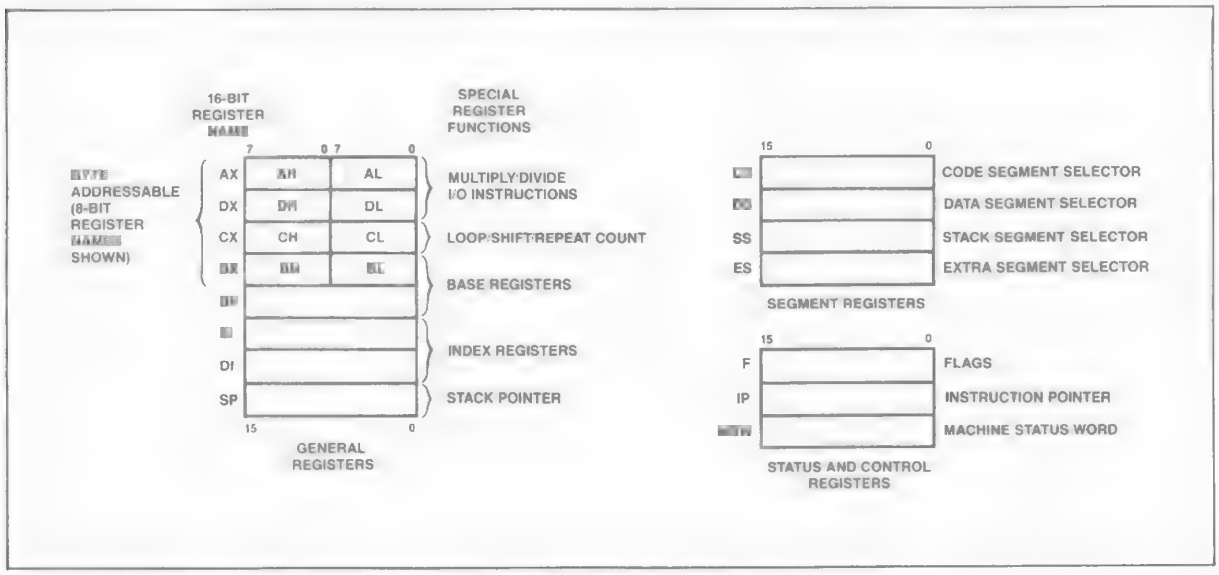


Figure 3. Register Set

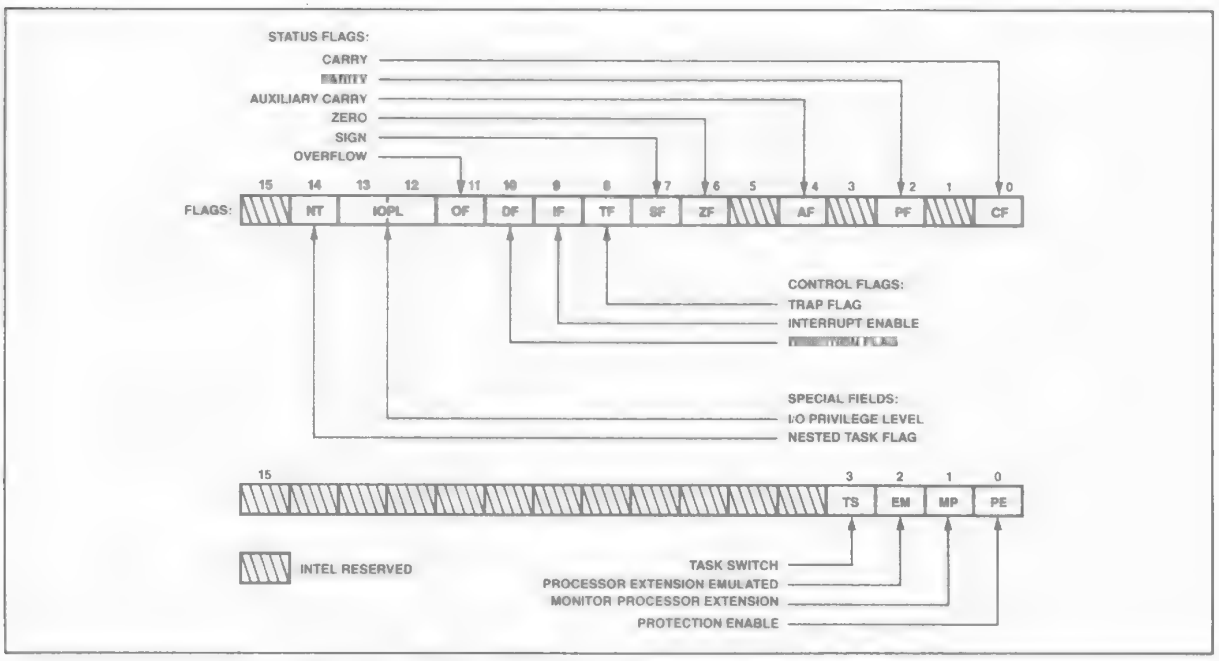


Figure 3a. Status and Control Register Bit Functions

Flags Word Description

The Flags word (Flags) records specific characteristics of the result of logical and arithmetic instructions (bits 0, 2, 4, 6, 7, and 11) and controls the operation of the 80286 within a given operating mode (bits 8 and 9). Flags is a 16-bit register. The function of the flag bits is given in Table 2.

Instruction Set

The instruction set is divided into seven categories: data transfer, arithmetic, shift/rotate/logical, string manipulation, control transfer, high level instructions, and processor control. These categories are summarized in Figure 4.

An 80286 instruction can reference zero, one, or two operands; where an operand resides in a register, in the instruction itself, or in memory. Zero-operand instructions (e.g. NOP and HLT) are usually one byte long. One-operand instructions (e.g. INC and DEC) are usually two bytes long but some are encoded in only one byte. One-operand instructions may reference a register or memory location. Two-operand instructions permit the following six types of instruction operations:

—Register to Register
—Memory to Register
—Immediate to Register
—Memory to Memory
—Register to Memory
—Immediate to Memory

Table 2. Flags Word Bit Functions

Bit Position	Name	Function
0	CF	Carry Flag—Set on high-order bit carry or borrow; cleared otherwise
2	PF	Parity Flag—Set if low-order 8 bits of result contain an even number of 1-bits; cleared otherwise
4	AF	Set on carry from or borrow to the low order four bits of AL; cleared otherwise
6	ZF	Zero Flag–Set if result is zero; cleared otherwise
7	SF	Sign Flag—Set equal to high-order bit of result (0 if positive, 1 if negative)
11	OF	Overflow Flag—Set if result is a too-large positive number or a too-small negative number (excluding sign-bit) to fit in destination operand; cleared otherwise
8	TF	Single Step Flag—Once set, a single step interrupt occurs after the next instruction executes. TF is cleared by the single step interrupt.
9	IF	Interrupt-enable Flag—When set, maskable interrupts will cause the CPU to transfer control to an interrupt vector specified location.
10	DF	Direction Flag—Causes string instructions to auto decrement the appropriate index registers when set. Clearing DF causes auto increment.

Two-operand instructions (e.g. MOV and ADD) are usually three to six bytes long. Memory to memory operations are provided by a special class of string instructions requiring one to three bytes. For detailed instruction formats and encodings refer to the instruction set summary at the end of this document.

GENERAL PURPOSE	
MOV	Move byte or word
PUSH	Push word onto stack
POP	Pop word off stack
PUSHA	Push all registers on stack
POPA	Pop all registers from stack
XCHG	Exchange byte or word
XLAT	Translate byte
INPUT/OUTPUT	
IN	Input byte or word
OUT	Output byte or word
ADDRESS OBJECT	
LEA	Load effective address
LDS	Load pointer using DS
LES	Load pointer using ES
FLAG TRANSFER	
LAHF	Load AH register from flags
SAHF	Store AH register in flags
PUSHF	Push flags onto stack
POPF	Pop flags off stack

Figure 4a. Data Transfer Instructions

MOVS	Move byte or word string
INS	Input bytes or word string
OUTS	Output bytes or word string
CMPS	Compare byte or word string
SCAS	Scan byte or word string
LODS	Load byte or word string
STOS	Store byte or word string
REP	Repeat
REPE/REPZ	Repeat while equal/zero
REPNE/REPNZ	Repeat while not equal/not zero

Figure 4c. String Instructions

ADDITION	
ADD	Add byte or word
ADC	Add byte or word with carry
INC	Increment byte or word by 1
AAA	ASCII adjust for addition
DAA	Decimal adjust for addition
SUBTRACTION	
SUB	Subtract byte or word
SBB	Subtract byte or word with borrow
DEC	Decrement byte or word by 1
NEG	Negate byte or word
CMP	Compare byte or word
AAS	ASCII adjust for subtraction
DAS	Decimal adjust for subtraction
MULTIPLICATION	
MUL	Multiply byte or word unsigned
IMUL	Integer multiply byte or word
AAM	ASCII adjust for multiply
DIVISION	
DIV	Divide byte or word unsigned
IDIV	Integer divide byte or word
AAD	ASCII adjust for division
CBW	Convert byte to word
CWD	Convert word to doubleword

Figure 4b. Arithmetic Instructions

LOGICALS	
NOT	"Not" byte or word
AND	"And" byte or word
OR	"Inclusive or" byte or word
XOR	"Exclusive or" byte or word
TEST	"Test" byte or word
SHIFTS	
SHL/SAL	Shift logical/arithmetic left byte or word
SHR	Shift logical right byte or word
SAR	Shift arithmetic right byte or word
ROTATES	
ROL	Rotate left byte or word
ROR	Rotate right byte or word
RCL	Rotate through carry left byte or word
RCR	Rotate through carry right byte or word

Figure 4d. Shift/Rotate/Logical Instructions

CONDITIONAL TRANSFERS		UNCONDITIONAL TRANSFERS	
JA/JNBE	Jump if above/not below nor equal	CALL	Call procedure
JAE/JNB	Jump if above or equal/not below	RET	Return from procedure
JB/JNAE	Jump if below/not above nor equal	JMP	Jump
JBE/JNA	Jump if below or equal/not above		
JC	Jump if carry	**ITERATION CONTROLS**	
JE/JZ	Jump if equal/zero		
JG/JNLE	Jump if greater/not less nor equal	LOOP	Loop
JGE/JNL	Jump if greater or equal/not less	LOOPE/LOOPZ	Loop if equal/zero
JL/JNGE	Jump if less/not greater nor equal	LOOPNE/LOOPNZ	Loop if not equal/not zero
JLE/JNG	Jump if less or equal/not greater	JCXZ	Jump if register CX = 0
JNC	Jump if not carry		
JNE/JNZ	Jump if not equal/not zero	**INTERRUPTS**	
JNO	Jump if not overflow		
JNP/JPO	Jump if not parity/parity odd	INT	Interrupt
JNS	Jump if not sign	INTO	Interrupt if overflow
JO	Jump if overflow	IRET	Interrupt return
JP/JPE	Jump if parity/parity even		
JS	Jump if sign		

Figure 4e. Program Transfer Instructions

FLAG OPERATIONS	
STC	Set carry flag
CLC	Clear carry flag
CMC	Complement carry flag
STD	Set direction flag
CLD	Clear direction flag
STI	Set interrupt enable flag
CLI	Clear interrupt enable flag
EXTERNAL SYNCHRONIZATION	
HLT	Halt until interrupt or reset
WAIT	Wait for $\overline{\text{BUSY}}$ not active
ESC	Escape to extension processor
LOCK	Lock bus during next instruction
NO OPERATION	
NOP	No operation
EXECUTION ENVIRONMENT CONTROL	
LMSW	Load machine status word
SMSW	Store machine status word

Figure 4f. Processor Control Instructions

ENTER	Format stack for procedure entry
LEAVE	Restore stack for procedure exit
BOUND	Detects values outside prescribed range

Figure 4g. High Level Instructions

Memory Organization

Memory is organized as sets of variable length segments. Each segment is a linear contiguous sequence of up to 64K (2^{16}) 8-bit bytes. Memory is addressed using a two-component address (a pointer) that consists of a 16-bit segment selector, and a 16-bit offset. The segment selector indicates the desired segment in memory. The offset component indicates the desired byte address within the segment.

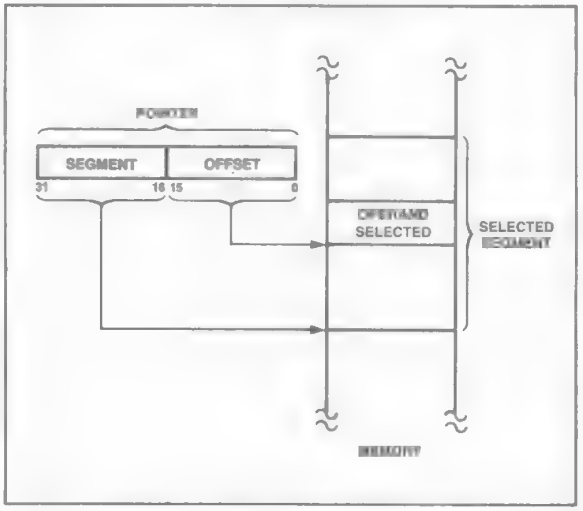


Figure 5. Two Component Address

Table 3. Segment Register Selection Rules

Memory Reference Needed	Segment Register Used	Implicit Segment Selection Rule
Instructions	Code (CS)	Automatic with instruction prefetch
Stack	Stack (SS)	All stack pushes and pops. Any memory reference which uses BP as a base register.
Local Data	Data (DS)	All data references except when relative to stack or string destination
External (Global) Data	Extra (ES)	Alternate data segment and destination of string operation

All instructions that address operands in memory must specify the segment and the offset. For speed and compact instruction encoding, segment selectors are usually stored in the high speed segment registers. An instruction need specify only the desired segment register and an offset in order to address a memory operand.

Most instructions need not explicitly specify which segment register is used. The correct segment register is automatically chosen according to the rules of Table 3. These rules follow the way programs are written (see Figure 6) as independent modules that require areas for code and data, a stack, and access to external data areas.

Special segment override instruction prefixes allow the implicit segment register selection rules to be overridden for special cases. The stack, data, and extra segments may coincide for simple programs. To access operands that do not reside in one of the four immediately available segments, either a full 32-bit pointer can be used or a new segment selector must be loaded.

Addressing Modes

The 80286 provides a total of eight addressing modes for instructions to specify operands. Two addressing modes are provided for instructions that operate on register or immediate operands:

Register Operand Mode: The operand is located in one of the 8 or 16-bit general registers.

Immediate Operand Mode. The operand is included in the instruction.

Six modes are provided to specify the location of an operand in a memory segment. A memory operand address consists of two 16-bit components: segment selector and offset. The segment selector is supplied by a segment register either implicitly chosen by the addressing mode or explicitly chosen by a segment override prefix. The offset is calculated by summing any combination of the following three address elements:

the **displacement** (an 8 or 16-bit immediate value contained in the instruction)

the **base** (contents of either the BX or BP base registers)

the **index** (contents of either the SI or DI index registers)

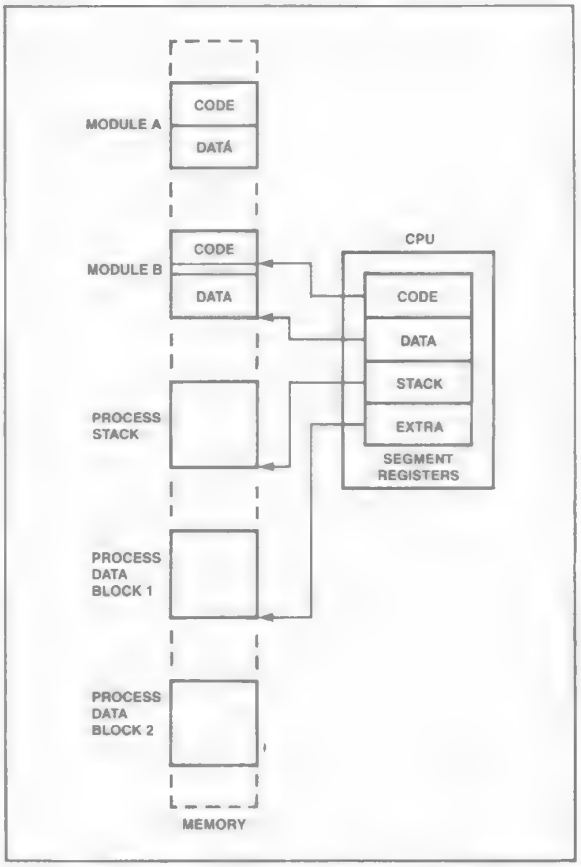


Figure 6. Segmented Memory Helps Structure Software

Any carry out from the 16-bit addition is ignored. Eight-bit displacements are sign extended to 16-bit values.

Combinations of these three address elements define the six memory addressing modes, described below.

Direct Mode: The operand's offset is contained in the instruction as an 8 or 16-bit displacement element.

Register Indirect Mode: The operand's offset is in one of the registers SI, DI, BX, or BP.

Based Mode: The operand's offset is the sum of an 8 or 16-bit displacement and the contents of a base register (BX or BP).

Indexed Mode: The operand's offset is the sum of an 8 or 16-bit displacement and the contents of an index register (SI or DI).

Based Indexed Mode: The operand's offset is the sum of the contents of a base register and an index register.

Based Indexed Mode with Displacement: The operand's offset is the sum of a base register's contents, an index register's contents, and an 8 or 16-bit displacement.

Data Types

The 80286 directly supports the following data types:

Integer: A signed binary numeric value contained in an 8-bit byte or a 16-bit word. All operations assume a 2's complement representation. Signed 32 and 64-bit integers are supported using the iAPX 286/20 Numeric Data Processor.

Ordinal: An unsigned binary numeric value contained in an 8-bit byte or 16-bit word.

Pointer: A 32-bit quantity, composed of a segment selector component and an offset component. Each component is a 16-bit word.

String: A contiguous sequence of bytes or words. A string may contain from 1 byte to 64K bytes.

ASCII: A byte representation of alphanumeric and control characters using the ASCII standard of character representation.

BCD: A byte (unpacked) representation of the decimal digits 0–9.

Packed BCD: A byte (packed) representation of two decimal digits 0–9 storing one digit in each nibble of the byte.

Floating Point: A signed 32, 64, or 80-bit real number representation. (Floating point operands are supported using the iAPX 286/20 Numeric Processor configuration.)

Figure 7 graphically represents the data types supported by the iAPX 286.

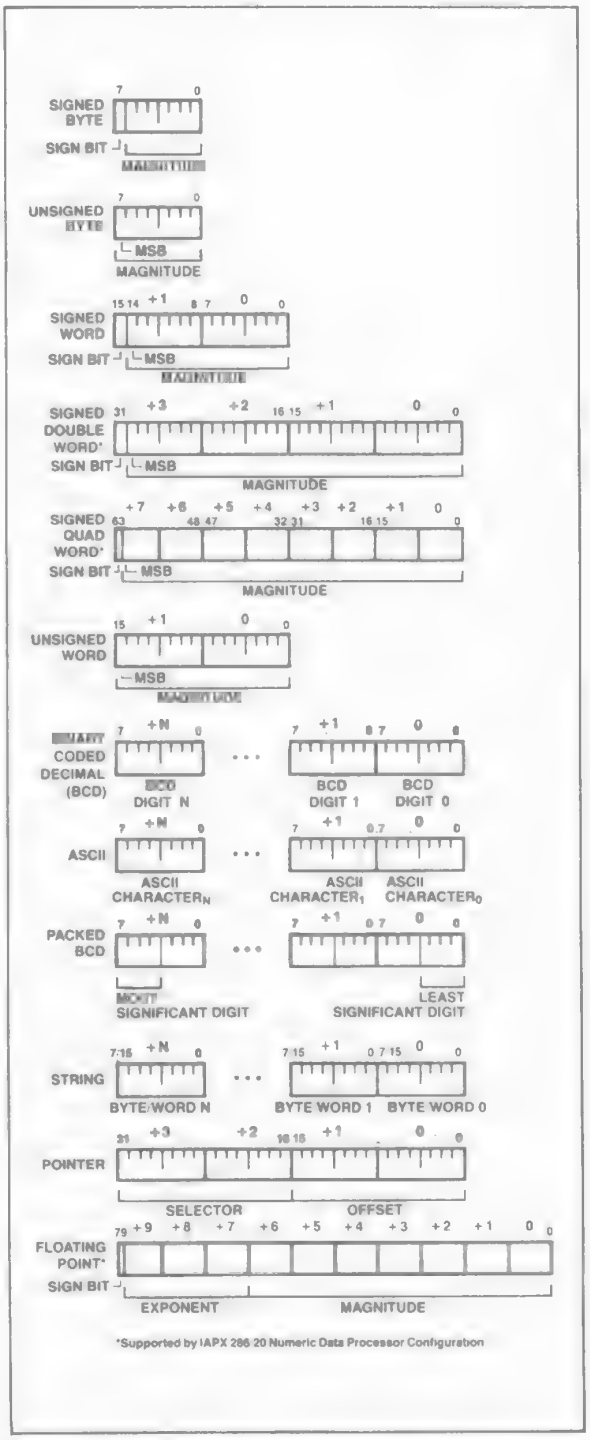


Figure 7. iAPX 286 Supported Data Types

I/O Space

The I/O space consists of 64K 8-bit or 32K 16-bit ports. I/O instructions address the I/O space with either an 8-bit port address, specified in the instruction, or a 16-bit port address in the DX register. 8-bit port addresses are zero extended such that A_{15}–A_8 are LOW. I/O port addresses 00F8(H) through 00FF(H) are reserved.

Table 4. Interrupt Vector Assignments

Function	Interrupt Number	Related Instructions	Return Address Before Instruction Causing Exception?
Divide error exception	0	DIV, IDIV	Yes
Single step interrupt	1	All	
NMI interrupt	2	All	
Breakpoint interrupt	3	INT	
INTO detected overflow exception	4	INTO	No
BOUND range exceeded exception	5	BOUND	Yes
Invalid opcode exception	6	Any undefined opcode	Yes
Processor extension not available exception	7	ESC or WAIT with	Yes
Reserved	8–15		
Processor extension error interrupt	16	ESC or WAIT	
Reserved	17–31		
User defined	32–255		

Interrupts

An interrupt transfers execution to a new program location. The old program address (CS:IP) and machine state (Flags) are saved on the stack to allow resumption of the interrupted program. Interrupts fall into three classes: hardware initiated, INT instructions, and instruction exceptions. Hardware initiated interrupts occur in response to an external input and are classified as non-maskable or maskable. Programs may cause an interrupt with an INT instruction. Instruction exceptions occur when an unusual condition, which prevents further instruction processing, is detected while attempting to execute an instruction. The return address from an exception will always point at the instruction causing the exception and include any leading instruction prefixes.

A table containing up to 256 pointers defines the proper interrupt service routine for each interrupt. Interrupts 0–31, some of which are used for instruction exceptions, are reserved. For each interrupt, an 8-bit vector must be supplied to the 80286 which identifies the appropriate table entry. Exceptions supply the interrupt vector internally. INT instructions contain or imply the vector and allow access to all 256 interrupts. Maskable hardware initiated interrupts supply the 8-bit vector to the CPU during an interrupt acknowledge bus sequence. Non-maskable hardware interrupts use a predefined internally supplied vector.

MASKABLE INTERRUPT (INTR)

The 80286 provides a maskable hardware interrupt request pin, INTR. Software enables this input by setting the interrupt flag bit (IF) in the flag word. All 224 user-defined interrupt sources can share this input, yet they can retain separate interrupt handlers. An 8-bit vector read by the CPU during the interrupt acknowledge sequence (discussed in System Interface section) identifies the source of the interrupt.

Further maskable interrupts are disabled while servicing an interrupt by resetting the IF but as part of the response to an interrupt or exception. The saved flag word will reflect the enable status of the processor prior to the interrupt. Until the flag word is restored to the flag register, the interrupt flag will be zero unless specifically set. The interrupt return instruction includes restoring the flag word, thereby restoring the original status of IF.

NON-MASKABLE INTERRUPT REQUEST (NMI)

A non-maskable interrupt input (NMI) is also provided. NMI has higher priority than INTR. A typical use of NMI would be to activate a power failure routine. The activation of this input causes an interrupt with an internally supplied vector value of 2. No external interrupt acknowledge sequence is performed.

While executing the NMI servicing procedure, the 80286 will service neither further NMI requests, INTR requests, nor the processor extension segment overrun interrupt until an interrupt return (IRET) instruction is executed or the CPU is reset. If NMI occurs while currently servicing an NMI, its presence will be saved for servicing after executing the first IRET instruction. IF is cleared at the beginning of an NMI interrupt to inhibit INTR interrupts.

SINGLE STEP INTERRUPT

The 80286 has an internal interrupt that allows programs to execute one instruction at a time. It is called the single step interrupt and is controlled by the single step flag bit (TF) in the flag word. Once this bit is set, an internal single step interrupt will occur after the next instruction has been executed. The interrupt clears the TF bit and uses an internally supplied vector of 1. The IRET instruction is used to set the TF bit and transfer control to the next instruction to be single stepped.

Interrupt Priorities

When simultaneous interrupt requests occur, they are processed in a fixed order as shown in Table 5. Interrupt processing involves saving the flags, return address, and setting CS:IP to point at the first instruction of the interrupt handler. If other interrupts remain enabled they are processed before the first instruction of the current interrupt handler is executed. The last interrupt processed is therefore the first one serviced.

Table 5. Interrupt Processing Order

Order	Interrupt
1	INT instruction or exception
2	Single step
3	NMI
4	Processor extension segment overrun
5	INTR

Initialization and Processor Reset

Processor initialization or start up is accomplished by driving the RESET input pin HIGH. RESET forces the 80286 to terminate all execution and local bus activity. No instruction or bus activity will occur as long as RESET is active. After RESET becomes inactive and an internal processing interval elapses, the 80286 begins execution in real address mode with the instruction at physical location FFFFF0(H). RESET also sets some registers to predefined values as shown as shown in Table 6.

Table 6. 80286 Initial Register State after RESET

Flag word	0002(H)
Machine Status Word	FFF0(H)
Instruction pointer	FFF0(H)
Code segment	F000(H)
Data segment	0000(H)
Extra segment	0000(H)
Stack segment	0000(H)

Machine Status Word Description

The machine status word (MSW) records when a task switch takes place and controls the operating mode of the 80286. It is a 16-bit register of which the lower four bits are used. One bit places the CPU into protected mode, while the other three bits, as shown in Table 7, control the processor extension interface. After RESET, this register contains FFF0(H) which places the 80286 in iAPX 86 real address mode.

Table 7. MSW Bit Functions

Bit Position	Name	Function
0	PE	Protected mode enable places the 80286 into protected mode and can not be cleared except by RESET.
1	MP	Monitor processor extension allows WAIT instructions to cause a processor extension not present exception (number 7).
2	EM	Emulate processor extension causes a processor extension not present exception (number 7) on ESC instructions to allow emulating a processor extension.
3	TS	Task switched indicates the next instruction using a processor extension will cause exception 7, allowing software to test whether the current processor extension context belongs to the current task.

The LMSW and SMSW instructions can load and store the MSW in real address mode. The recommended use of TS, EM, and MP is shown in Table 8.

Table 8. Recommended MSW Encodings For Processor Extension Control

TS	MP	EM	Recommended Use	Instructions Causing Exception
0	0	0	iAPX 86 real address mode only. Initial encoding after RESET. iAPX 286 operation is identical to iAPX 86, 88.	None
0	0	1	No processor extension is available. Software will emulate its function.	ESC
1	0	1	No processor extension is available. Software will emulate its function. The current processor extension context may belong to another task.	ESC
0	1	0	A processor extension exists.	None
1	1	0	A processor extension exists. The current processor extension context may belong to another task. The exception on WAIT allows software to test for an error pending from a previous processor extension operation.	ESC or WAIT

Halt

The HLT instruction stops program execution and prevents the CPU from using the local bus until restarted. Either NMI, INTR with IF = 1, or RESET will force the 80286 out of halt. If interrupted, the saved CS:IP will point to the next instruction after the HLT.

iAPX 86 REAL ADDRESS MODE

The 80286 executes a fully upward-compatible superset of the 8086 instruction set in real address mode. In real address mode the 80286 is object code compatible with 8086 and 8088 software. The real address mode architecture (registers and addressing modes) is exactly as described in the iAPX 286/10 Base Architecture section of this Functional Description.

Memory Size

Physical memory is a contiguous array of up to 1,048,576 bytes (one megabyte) addressed by pins A_0 through A_{19} and $\overline{BHE}$. A_{20} through A_{23} are ignored.

Memory Addressing

In real address mode the processor generates 20-bit physical addresses directly from a 20-bit segment base address and a 16-bit offset.

The selector portion of a pointer is interpreted as the upper 16 bits of a 20-bit segment address. The lower four bits of the 20-bit segment address are always zero. Segment addresses, therefore, begin on multiples of 16 bytes. See Figure 8 for a graphic representation of address formation.

All segments in real address mode are 64K bytes in size and may be read, written, or executed. An exception or interrupt can occur if data operands or instructions attempt to wrap around the end of a segment (e.g. a word with its low order byte at offset FFFF(H) and its high order byte at offset 0000(H)). If, in real address mode, the information contained in a segment does not use the full 64K bytes, the unused end of the segment may be overlayed by another segment to reduce physical memory requirements.

Reserved Memory Locations

The 80286 reserves two fixed areas of memory in real address mode (see Figure 9); system initialization area and interrupt table area. Locations from addresses FFFF0(H) thorugh FFFFF(H) are reserved for system initialization. Initial execution begins at location FFFF0(H). Locations 00000(H) through 003FF(H) are reserved for interrupt vectors.

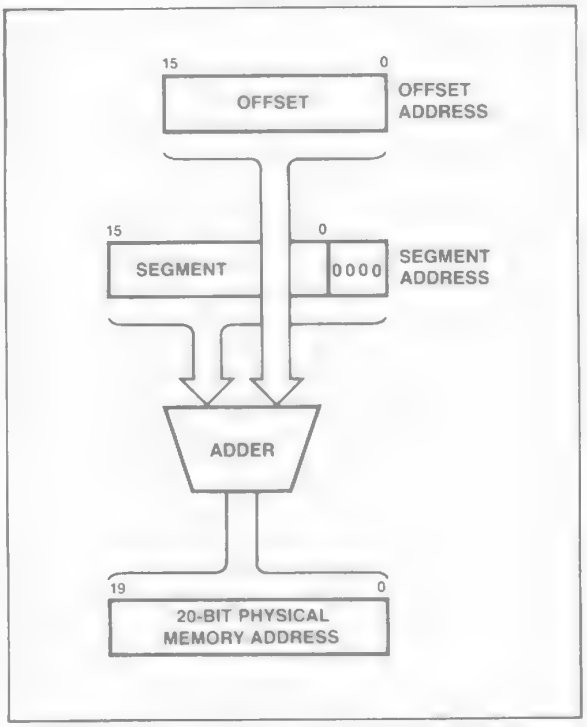


Figure 8. iAPX 86 Real Address Mode Address Calculation

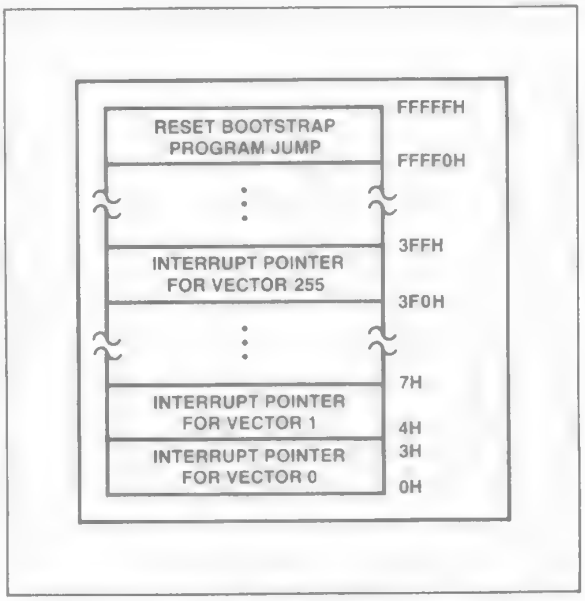


Figure 9. iAPX 86 Real Address Mode Initially Reserved Memory Locations

Table 9. Real Address Mode Addressing Interrupts

Function	Interrupt Number	Related Instructions	Return Address Before Instruction?
Interrupt table limit too small exception	8	INT vector is not within table limit	Yes
Processor extension segment overrun interrupt	9	ESC with memory operand extending beyond offset FFFF(H)	No
Segment overrun exception	13	Word memory reference with offset = FFFF(H) or an attempt to execute past the end of a segment	Yes

Interrupts

Table 9 shows the interrupt vectors reserved for exceptions and interrupts which indicate an addressing error. The exceptions leave the CPU in the state existing before attempting to execute the failing instruction (except for PUSH, POP, PUSHA, or POPA). Refer to the next section on protected mode initialization for a discussion on exception 8.

Protected Mode Initialization

To prepare the 80286 for protected mode, the LIDT instruction is used to load the 24-bit interrupt table base and 16-bit limit for the protected mode interrupt table. This instruction can also set a base and limit for the interrupt vector table in real address mode. After reset, the interrupt table base is initialized to 000000(H) and its size set to 03FF(H). These values are compatible with iAPX 86, 88 software. LIDT should only be executed in preparation for protected mode.

Shutdown

Shutdown occurs when a severe error is detected that prevents further instruction processing by the CPU. Shutdown and halt are externally signalled via a halt bus operation. They can be distinguished by A_1 HIGH for halt and A_1 LOW for shutdown. In real address mode, shutdown can occur under two conditions:

- Exceptions 8 or 13 happen and the IDT limit does not include the interrupt vector.
- A CALL, INT, or POP instruction attempts to wrap around the stack segment when SP is not even.

An NMI input can bring the CPU out of shutdown if the IDT limit is at least 000F(H) and SP is greater than 0005(H), otherwise shutdown can only be exited via the RESET input.

PROTECTED VIRTUAL ADDRESS MODE

The 80286 executes a fully upward-compatible superset of the 8086 instruction set in protected virtual address mode (protected mode). Protected mode also provides memory management and protection mechanisms and associated instructions.

The 80286 enters protected virtual address mode from real address mode by setting the PE (Protection Enable) bit of the machine status word with the Load Machine Status Word (LMSW) instruction. Protected mode offers extended physical and virtual memory address space, memory protection mechanisms, and new operations to support operating systems and virtual memory.

All registers, instructions, and addressing modes described in the iAPX 286/10 Base Architecture section of this Functional Description remain the same. Programs for the iAPX 86, 88, 186, and real address mode 80286 can be run in protected mode; however, embedded constants for segment selectors are different.

Memory Size

The protected mode 80286 provides a 1 gigabyte virtual address space per task mapped into a 16 megabyte physical address space defined by the address pins A_{23}–A_0 and $\overline{BHE}$. The virtual address space may be larger than the physical address space since any use of an address that does not map to a physical memory location will cause a restartable exception.

Memory Addressing

As in real address mode, protected mode uses 32-bit pointers, consisting of 16-bit selector and offset components. The selector, however, specifies an index into a memory resident table rather than the upper 16-bits of a real memory address. The 24-bit base address of the

desired segment is obtained from the tables in memory. The 16-bit offset is added to the segment base address to form the physical address as shown in Figure 10. The tables are automatically referenced by the CPU whenever a segment register is loaded with a selector. All iAPX 286 instructions which load a segment register will reference the memory based tables without additional software. The memory based tables contain 8 byte values called descriptors.

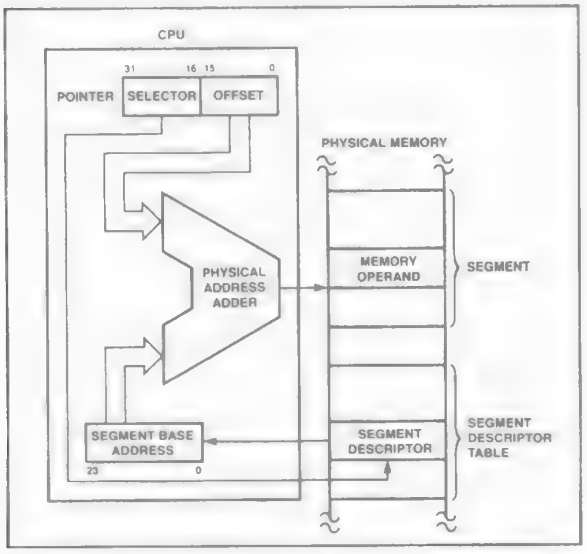


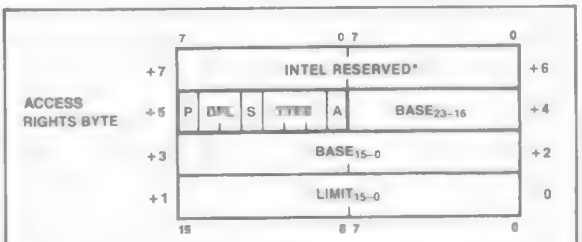
Figure 10. Protected Mode Memory Addressing

DESCRIPTORS

Descriptors define the use of memory. Special types of descriptors also define new functions for transfer of control and task switching. The 80286 has segment descriptors for code, stack and data segments, and system control descriptors for special system data segments and control transfer operations. Descriptor accesses are performed as locked bus operations to assure descriptor integrity in multi-processor systems.

CODE AND DATA SEGMENT DESCRIPTORS

Besides segment base addresses, code and data descriptors contain other segment attributes including segment size (1 to 64K bytes), access rights (read only, read/write, execute only, and execute/read), and presence in memory (for virtual memory systems) (See Figure 11). Any segment usage violating a segment attribute indicated by the segment descriptor will prevent the memory cycle and cause an exception or interrupt.



*Must be set to 0 for compatability with iAPX 386.

Access Rights Byte Definition

Bit Position	Name	Function	
7	Present (P)	P=1 Segment is mapped into physical memory. P=0 No mapping to physical memory exists, base and limit are not used.	
6–5	Descriptor Privilege Level (DPL)	Segment privilege attribute used in privilege tests.	
4	Segment Descriptor (S)	S=1 Code or Data segment descriptor S=0 Non-segment descriptor	
3	Executable (E)	E=0 Data segment descriptor type is:	Data Segment
2	Expansion Direction (ED)	ED=0 Grow up segment, offsets must be ≤ limit. ED=1 Grow down segment, offsets must be > limit.	Data Segment
1	Writeable (W)	W=0 Data segment may not be written into. W=1 Data segment may be written into.	Data Segment
3	Executable (E)	E=1 Code Segment Descriptor type is:	Code Segment
2	Conforming (C)	C=1 Code segment may only be executed when CPL ≥ DPL.	Code Segment
1	Readable (R)	R=0 Code segment may not be read. R=1 Code segment may be read.	Code Segment
0	Accessed (A)	A=0 Segment has not been accessed. A=1 Segment selector has been loaded into segment register or used by selector test instructions.	

Type Field Definition

Figure 11. Code and Data Segment Descriptors

Code and data are stored in two types of segments: code segments and data segments. Both types are identified and defined by segment descriptors. Code segments are identified by the executable (E) bit set to 1 in the descriptor access rights byte. The access rights byte of both code and data segment descriptor types have three fields in common: present (P) bit, Descriptor Privilege Level (DPL), and accessed (A) bit. If P = 0, any attempted use of this segment will cause a not-present exception. DPL specifies the privilege level of the segment descriptor. DPL effects when the descriptor may be used by a task (refer to privilege discussion below). The A bit shows whether the segment has been previously accessed for usage profiling, a necessity for virtual memory systems. The CPU will always set this bit when accessing the descriptor.

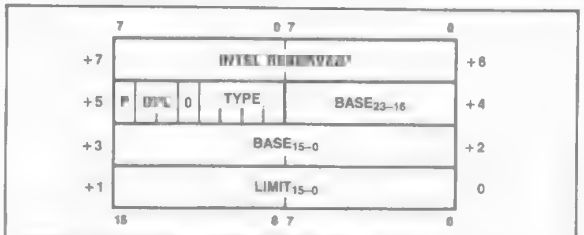
Data segments (S = 1, E = 0) may be either read-only or read-write as controlled by the W bit of the access rights byte. Read-only (W = 0) data segments may not be written into. Data segments may grow in two directions, as determined by the Expansion Direction (ED) bit: upwards (ED = 0) for data segments, and downwards (ED = 1) for a segment containing a stack. The limit field for a data segment descriptor is interpreted differently depending on the ED bit (see Figure 11).

A code segment (S = 1, E = 1) may be execute-only or execute/read as determined by the Readable (R) bit. Code segments may never be written into and execute-only code segments (R = 0) may not be read. A code segment may also have an attribute called conforming (C). A conforming code segment may be shared by programs that execute at different privilege levels. The DPL of a conforming code segment defines the range of privilege levels at which the segment may be executed (refer to privilege discussion below).

SYSTEM CONTROL DESCRIPTORS

In addition to code and data segment descriptors, the protected mode 80286 defines system control descriptors. These descriptors define special system data segments and control transfer mechanisms in the protected environment. The special system data segment descriptors define segments which contain tables of descriptors (Local Descriptor Table Descriptor) and segments which contain the execution state of a task (Task State Segment Descriptor).

The control transfer descriptors are call gates, task gates, interrupt gates and trap gates. Gates provide a level of indirection between the source and destination of the control transfer. This indirection allows the CPU to automatically perform protection checks and control the entry point of the destination. Call gates are used to change privilege levels (see Privilege), task gates are used to perform a task switch, and interrupt and trap



*Must be set to 0 for compatability with iAPX 386.

System Segment Descriptor Fields

Name	Value	Description
TYPE	1 2 3	Available Task State Segment Local Descriptor Table Descriptor Busy Task State Segment
P	0 1	Descriptor contents are not valid Descriptor contents are valid
DPL	0–3	Descriptor Privilege Level
BASE	24-bit number	Base Address of special system data segment in real memory
LIMIT	16-bit number	Offset of last byte in segment

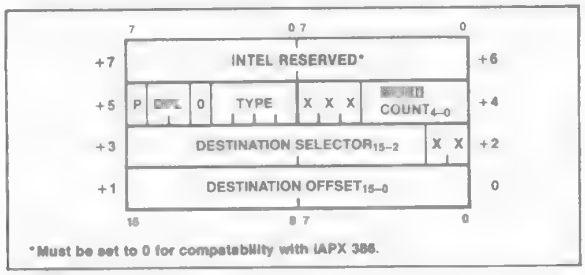
Figure 12. Special System Data Segment

gates are used to specify interrupt service routines. The interrupt gate disables interrupts (resets IF) while the trap gate does not.

Figure 12 gives the formats for the special system data segment descriptors. The descriptors contain a 24-bit base address of the segment and a 16-bit limit. The access byte defines the type of descriptor, its state and privilege level. The descriptor contents are valid and the segment is in physical memory if P = 1. If P = 0, the segment is not valid. The DPL field is only used in Task State Segment descriptors and indicates the privilege level at which the descriptor may be used (see Privilege). Since the Local Descriptor Table descriptor may only be used by a special privileged instruction, the DPL field is not used. Bit 4 of the access byte is 0 to indicate that it is a system control descriptor. The type field specifies the descriptor type as indicated in Figure 12.

Figure 13 shows the format of the gate descriptors. The descriptor contains a destination pointer that points to the descriptor of the target segment and the entry point offset. The destination selector in an interrupt gate, trap gate, and call gate must refer to a code segment descriptor. These gate descriptors contain the entry point to prevent a program from constructing and using an illegal entry point. Task gates may only refer to a task state segment. Since task gates invoke a task switch, the destination offset is not used in the task gate.

Exception 13 is generated when the gate is used if a destination selector does not refer to the correct de-



Gate Descriptor Fields

Name	Value	Description
TYPE	4 5 6 7	–Call Gate –Task Gate –Interrupt Gate –Trap Gate
P	0 1	–Descriptor Contents are not valid –Descriptor Contents are valid
DPL	0–3	Descriptor Privilege Level
WORD COUNT	0–31	Number of words to copy from callers stack to called procedures stack. Only used with call gate.
DESTINATION SELECTOR	16-bit selector	Selector to the target code segment (Call, Interrupt or Trap Gate) Selector to the target task state segment (Task Gate)
DESTINATION OFFSET	16-bit offset	Entry point within the target code segment

Figure 13. Gate Descriptor Format

scriptor type. The word count field is used in the call gate descriptor to indicate the number of parameters (0–31 words) to be automatically copied from the caller's stack to the stack of the called routine when a control transfer changes privilege levels. The word count field is not used by any other gate descriptor.

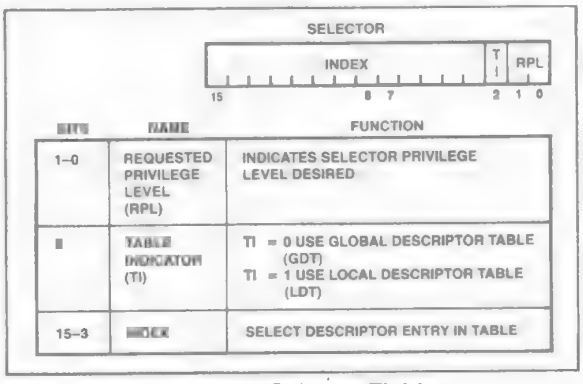
The access byte format is the same for all gate descriptors. P = 1 indicates that the gate contents are valid. P = 0 indicates the contents are not valid and causes exception 11 if referenced. DPL is the descriptor privilege level and specifies when this descriptor may be used by a task (refer to privilege discussion below). Bit 4 must equal 0 to indicate a system control descriptor. The type field specifies the descriptor type as indicated in Figure 13.

SEGMENT DESCRIPTOR CACHE REGISTERS

A segment descriptor cache register is assigned to each of the four segment registers (CS, SS, DS, ES). Segment descriptors are automatically loaded (cached) into a segment descriptor cache register (Figure 14) whenever the associated segment register is loaded with a selector. Only segment descriptors may be loaded into segment descriptor cache registers. Once loaded, all references to that segment of memory use the cached descriptor information instead of reaccessing memory. The descriptor cache registers are not visible to programs. No instructions exist to store their contents. They only change when a segment register is loaded.

SELECTOR FIELDS

A protected mode selector has three fields: descriptor entry index, local or global descriptor table indicator (TI), and selector privilege (RPL) as shown in Figure 15. These fields select one of two memory based tables of descriptors, select the appropriate table entry and allow high-speed testing of the selector's privilege attribute (refer to privilege discussion below).



BITS	NAME	FUNCTION
1–0	REQUESTED PRIVILEGE LEVEL (RPL)	INDICATES SELECTOR PRIVILEGE LEVEL DESIRED
2	TABLE INDICATOR (TI)	TI = 0 USE GLOBAL DESCRIPTOR TABLE (GDT) TI = 1 USE LOCAL DESCRIPTOR TABLE (LDT)
15–3	INDEX	SELECT DESCRIPTOR ENTRY IN TABLE

Figure 15. Selector Fields

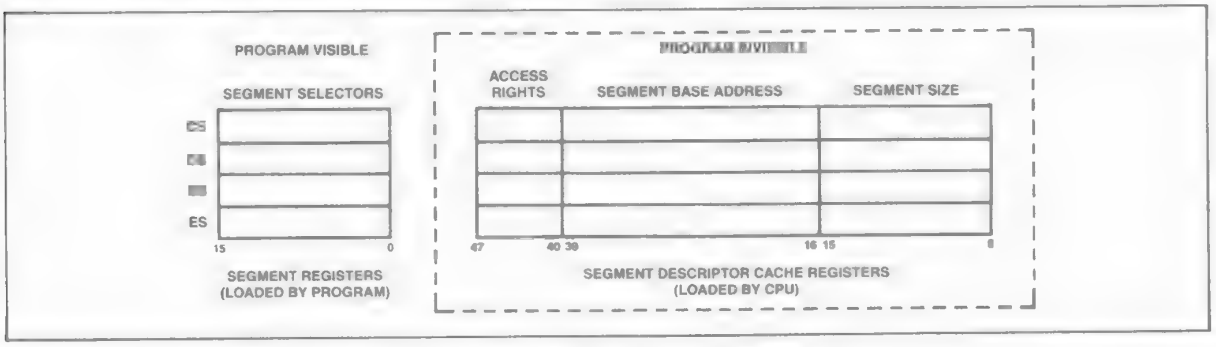


Figure 14. Descriptor Cache Registers

LOCAL AND GLOBAL DESCRIPTOR TABLES

Two tables of descriptors, called descriptor tables, contain all descriptors accessible by a task at any given time. A descriptor table is a linear array of up to 8192 descriptors. The upper 13 bits of the selector value are an index into a descriptor table. Each table has a 24-bit base register to locate the descriptor table in physical memory and a 16-bit limit register that confine descriptor access to the defined limits of the table as shown in Figure 16. A restartable exception (13) will occur if an attempt is made to reference a descriptor outside the table limits.

One table, called the Global Descriptor Table (GDT), contains descriptors available to all tasks. The other table, called the Local Descriptor Table (LDT), contains descriptors that can be private to a task. Each task may have its own private LDT. The GDT may contain all descriptor types except interrupt and trap descriptors. The LDT may contain only segment, task gate, and call gate descriptors. A segment cannot be accessed by a task if its segment descriptor does not exist in either descriptor table at the time of access.

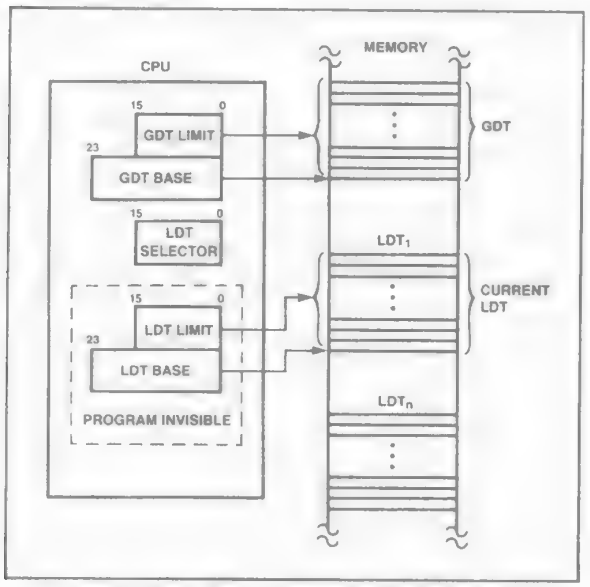


Figure 16. Local and Global Descriptor Table Definition

The LGDT and LLDT instructions load the base and limit of the global and local descriptor tables. LGDT and LLDT are protected. They may only be executed by trusted programs operating at level 0. The LGDT instruction loads a six byte field containing the 16-bit table limit and 24-bit base address of the Global Descriptor Table as shown in Figure 17. The LLDT instruction loads a selector which refers to a Local Descriptor Table descriptor containing the base address and limit for an LDT, as shown in Figure 12.

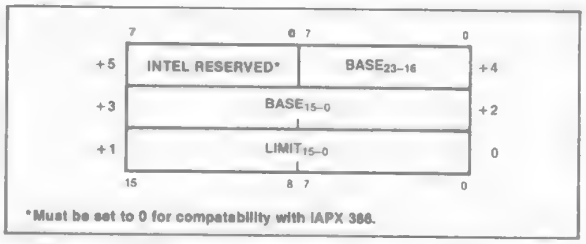


Figure 17. Global Descriptor Table and Interrupt Descriptor Data Type

INTERRUPT DESCRIPTOR TABLE

The protected mode 80286 has a third descriptor table, called the Interrupt Descriptor Table (IDT) (see Figure 18), used to define up to 256 interrupts. It may contain only task gates, interrupt gates and trap gates. The IDT (Interrupt Descriptor Table) has a 24-bit base and 16-bit limit register in the CPU. The protected LIDT instruction loads these registers with a six byte value of identical form to that of the LGDT instruction (see Figure 17 and Protected Mode Initialization).

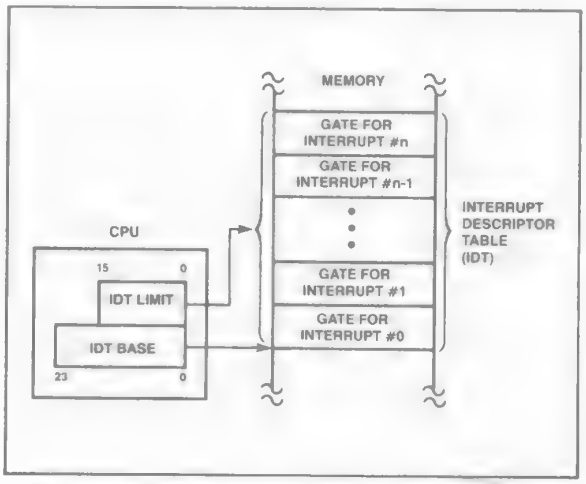


Figure 18. Interrupt Descriptor Table Definition

References to IDT entries are made via INT instructions, external interrupt vectors, or exceptions. The IDT must be at least 256 bytes in size to allocate space for all reserved interrupts.

Privilege

The 80286 has a four-level hierarchical privilege system which controls the use of privileged instructions and access to descriptors (and their associated segments) within a task. Four-level privilege, as shown in Figure 19, is an extension of the user/supervisor mode commonly found in minicomputers. The privilege levels are numbered 0 through 3. Level 0 is the most privileged level. Privilege

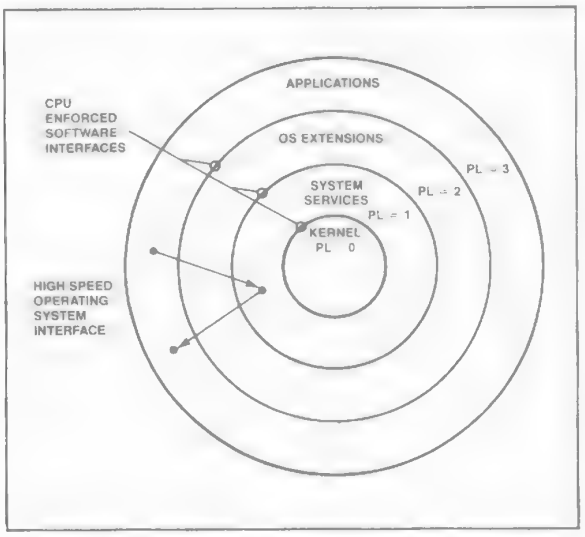


Figure 19. Hierarchical Privilege Levels

levels provide protection within a task. (Tasks are isolated by providing private LDT's for each task.) Operating system routines, interrupt handlers, and other system software can be included and protected within the virtual address space of each task using the four levels of privilege. Tasks may also have a separate stack for each privilege level.

Tasks, descriptors, and selectors have a privilege level attribute that determines whether the descriptor may be used. Task privilege effects the use of instructions and descriptors. Descriptor and selector privilege only effect access to the descriptor.

TASK PRIVILEGE

A task always executes at one of the four privilege levels. The task privilege level at any specific instant is called the Current Privilege Level (CPL) and is defined by the lower two bits of the CS register. CPL cannot change during execution in a single code segment. A task's CPL may only be changed by control transfers through gate descriptors to a new code segment (See Control Transfer). Tasks begin executing at the CPL value specified by the code segment when the task is initiated via a task switch operation. A task executing at Level 0 can access all data segments defined in the GDT and the task's LDT and is considered the most trusted level. A task executing at Level 3 has the most restricted access to data and is considered the least trusted level.

DESCRIPTOR PRIVILEGE

Descriptor privilege is specified by the Descriptor Privilege Level (DPL) field of the descriptor access byte. DPL specifies the least trusted task privilege level (CPL) at which a task may access the descriptor. Descriptors with DPL = 0 are the most protected. Only tasks executing at privilege level 0 (CPL = 0) may access them. Descriptors with DPL = 3 are the least protected (i.e. have the least restricted access) since tasks can access them when CPL = 0, 1, 2, or 3. This rule applies to all descriptors, except LDT descriptors.

SELECTOR PRIVILEGE

Selector privilege is specified by the Requested Privilege Level (RPL) field in the least significant two bits of a selector. Selector RPL may establish a less trusted privilege level than the current privilege level for the use of a selector. This level is called the task's effective privilege level (EPL). RPL can only reduce the scope of a task's access to data with this selector. A task's effective privilege is the numeric maximum of RPL and CPL. A selector with RPL = 0 imposes no additional restriction on its use while a selector with RPL = 3 can only refer to segments at privilege Level 3 regardless of the task's CPL. RPL is generally used to verify that pointer parameters passed to a more trusted procedure are not allowed to use data at a more privileged level than the caller (refer to pointer testing instructions).

Descriptor Access and Privilege Validation

Determining the ability of a task to access a segment involves the type of segment to be accessed, the instruction used, the type of descriptor used and CPL, RPL, and DPL. The two basic types of segment accesses are control transfer (selectors loaded into CS) and data (selectors loaded into DS, ES or SS).

DATA SEGMENT ACCESS

Instructions that load selectors into DS and ES must refer to a data segment descriptor or readable code segment descriptor. The CPL of the task and the RPL of the selector must be the same as or more privileged (numerically equal to or lower than) than the descriptor DPL. In general, a task can only access data segments at the same or less privileged levels than the CPL or RPL (whichever is numerically higher) to prevent a program from accessing data it cannot be trusted to use.

An exception to the rule is a readable conforming code segment. This type of code segment can be read from any privilege level.

If the privilege checks fail (e.g. DPL is numerically less than the maximum of CPL and RPL) or an incorrect type of descriptor is referenced (e.g. gate descriptor or execute only code segment) exception 13 occurs. If the segment is not present, exception 11 is generated.

Instructions that load selectors into SS must refer to data segment descriptors for writable data segments. The descriptor privilege (DPL) and RPL must equal CPL. All other descriptor types or a privilege level violation will cause exception 13. A not present fault causes exception 12.

CONTROL TRANSFER

Four types of control transfer can occur when a selector is loaded into CS by a control transfer operation (see Table 10). Each transfer type can only occur if the operation which loaded the selector references the correct descriptor type. Any violation of these descriptor usage rules (e.g. JMP through a call gate or RET to a Task State Segment) will cause exception 13.

The ability to reference a descriptor for control transfer is also subject to rules of privilege. A CALL or JUMP instruction may only reference a code segment descriptor with DPL equal to the task CPL or a conforming segment with DPL of equal or greater privilege than CPL. The RPL of the selector used to reference the code descriptor must have as much privilege as CPL.

RET and IRET instructions may only reference code segment descriptors with descriptor privilege equal to or less privileged than the task CPL. The selector loaded into CS is the return address from the stack. After the return, the selector RPL is the task's new CPL. If CPL changes, the old stack pointer is popped after the return address.

When a JMP or CALL references a Task State Segment descriptor, the descriptor DPL must be the same or less privileged than the task's CPL. Reference to a valid Task State Segment descriptor causes a task switch (see Task Switch Operation). Reference to a Task State Segment descriptor at a more privileged level than the task's CPL generates exception 13.

When an instruction or interrupt references a gate descriptor, the gate DPL must have the same or less privilege than the task CPL. If DPL is at a more privileged level than CPL, exception 13 occurs. If the destination selector contained in the gate references a code segment descriptor, the code segment descriptor DPL must be the same or more privileged than the task CPL. If not, Exception 13 is issued. After the control transfer, the code segment descriptors DPL is the task's new CPL. If the destination selector in the gate references a task state segment, a task switch is automatically performed (see Task Switch Operation).

The privilege rules on control transfer require:

—JMP or CALL direct to a code segment (code segment descriptor) can only be to a conforming segment with DPL of equal or greater privilege than CPL or a non-conforming segment at the same privilege level.

—interrupts within the task or calls that may change privilege levels, can only transfer control through a gate at the same or a less privileged level than CPL to a code segment at the same or more privileged level than CPL.

—return instructions that don't switch tasks can only return control to a code segment at the same or less privileged level.

—task switch can be performed by a call, jump or interrupt which references either a task gate or task state segment at the same or less privileged level.

Table 10. Descriptor Access Rules for Control Transfer

Control Transfer Types	Operation Types	Descriptor Referenced	Descriptor Table
Intersegment within the same privilege level	JMP, CALL, RET, IRET*	Code Segment	GDT/LDT
Intersegment to the same or higher privilege level Interrupt within task may change CPL.	CALL	Call Gate	GDT/LDT
	Interrupt Instruction, Exception, External Interrupt	Trap or Interrupt Gate	IDT
Intersegment to a lower privilege level (changes task CPL)	RET, IRET*	Code Segment	GDT/LDT
Task Switch	CALL, JMP	Task State Segment	GDT
	CALL, JMP	Task Gate	GDT/LDT
	IRET** Interrupt Instruction, Exception, External Interrupt	Task Gate	IDT

*NT (Nested Task bit of flag word) = 0
**NT (Nested Task bit of flag word) = 1

PRIVILEGE LEVEL CHANGES

Any control transfer that changes CPL within the task, causes a change of stacks as part of the operation. Initial values of SS:SP for privilege levels 0, 1, and 2 are kept in the task state segment (refer to Task Switch Operation). During a JMP or CALL control transfer, the new stack pointer is loaded into the SS and SP registers and the previous stack pointer is pushed onto the new stack.

When returning to the original privilege level, its stack is restored as part of the RET or IRET instruction operation. For subroutine calls that pass parameters on the stack and cross privilege levels, a fixed number of words, as specified in the gate, are copied from the previous stack to the current stack. The inter-segment RET instruction with a stack adjustment value will correctly restore the previous stack pointer upon return.

Protection

The 80286 includes mechanisms to protect critical instructions that affect the CPU execution state (e.g. HLT) and code or data segments from improper usage. These mechanisms are grouped under the term "protection" and have three forms:

Restricted usage of segments (e.g. no write allowed to read-only data segments). The only segments available for use are defined by descriptors in the Local Descriptor Table (LDT) and Global Descriptor Table (GDT).

Restricted access to segments via the rules of privilege and descriptor usage.

Privileged instructions or operations that may only be executed at certain privilege levels as determined by the CPL and I/O Privilege Level (IOPL). The IOPL is defined by bits 14 and 13 of the flag word.

These checks are performed for all instructions and can be split into three categories: segment load checks (Table 11), operand reference checks (Table 12), and privileged instruction checks (Table 13). Any violation of the rules shown will result in an exception. A not-present exception related to the stack segment causes exception 12.

The IRET and POPF instructions do not perform some of their defined functions if CPL is not of sufficient privilege (numerically small enough). No exceptions or other indication are given when these conditions occur.

The IF bit is not changed if CPL > IOPL.

The IOPL field of the flag word is not changed if CPL > 0.

Table 11
Segment Register Load Checks

Error Description	Exception Number
Descriptor table limit exceeded	13
Segment descriptor not-present	11 or 12
Privilege rules violated	13
Invalid descriptor/segment type segment register load: —Read only data segment load to SS —Special control descriptor load to DS, ES, SS —Execute only segment load to DS, ES, SS —Data segment load to CS —Read/Execute code segment load to SS	13

Table 12 Operand Reference Checks

Error Description	Exception Number
Write into code segment	13
Read from execute-only code segment	13
Write to read-only data segment	13
Segment limit exceeded[1]	12 or 13

Note 1: Carry out in offset calculations is ignored.

Table 13. Privileged Instruction Checks

Error Description	Exception Number
CPL ≠ 0 when executing the following instructions: LIDT, LLDT, LGDT, LTR, LMSW, CTS, HLT	13
CPL > IOPL when executing the following instructions: INS, IN, OUTS, OUT, STI, CLI, LOCK	13

EXCEPTIONS

The 80286 detects several types of exceptions and interrupts, in protected mode (see Table 14). Most are restartable after the exceptional condition is removed. Interrupt handlers for most exceptions receive an error code, pushed on the stack after the return address, that identifies the selector involved (0 if none). The return address normally points to the failing instruction, including all leading prefixes. For a processor extension segment overrun exception, the return address will not point at the ESC instruction that caused the exception; however, the processor extension registers may contain the address of the failing instruction.

Table 14. Protected Mode Exceptions

Interrupt Vector	Function	Return Address At Failing Instruction?	Always Restart-able?	Error Code on Stack?
8	Double exception detected	Yes	No	Yes
9	Processor extension segment overrun	No	No	No
10	Invalid task state segment	Yes	Yes	Yes
11	Segment not present	Yes	Yes	Yes
12	Stack segment overrun or segment not present	Yes	Yes[1]	Yes
13	General protection	Yes	No	Yes

Note 1: When a PUSHA or POPA instruction attempts to wrap around the stack segment, the machine state after the exception will not be restartable. This condition is identified by the value of the saved SP being either 0000(H), 0001(H), FFFE(H), or FFFF(H).

All these checks are performed for all instructions and can be split into three categories: segment load checks (Table 11), operand reference checks (Table 12), and privileged instruction checks (Table 13). Any violation of the rules shown will result in an exception. A not-present exception related to the stack segment causes exception 12.

Special Operations

TASK SWITCH OPERATION

The 80286 provides a built-in task switch operation which saves the entire 80286 execution state (registers, address space, and a link to the previous task), loads a new execution state, and commences execution in the new task. Like gates, the task switch operation is invoked by executing an inter-segment JMP or CALL instruction which refers to a Task State Segment (TSS) or task gate descriptor in the GDT or LDT. An INT n instruction, exception, or external interrupt may also invoke the task switch operation by selecting a task gate descriptor in the associated IDT descriptor entry.

The TSS descriptor points at a segment (see Figure 20) containing the entire 80286 execution state while a task gate descriptor contains a TSS selector. The limit field must be > 002B(H).

Each task must have a TSS associated with it. The current TSS is identified by a special register in the 80286 called the Task Register (TR). This register contains a selector referring to the task state segment descriptor that defines the current TSS. A hidden base and limit register associated with TR are loaded whenever TR is loaded with a new selector.

The IRET instruction is used to return control to the task that called the current task or was interrupted. Bit 14 in the flag register is called the Nested Task (NT) bit. It controls the function of the IRET instruction. If NT = 0, the IRET instruction performs the regular current task return; when NT = 1, IRET performs a task switch operation back to the previous task.

When a CALL or INT instruction initiates a task switch, the old and new TSS will be marked busy and the back link field of the new TSS set to the old TSS selector. The NT bit of the new task is set by CALL or INT initiated task switches. An interrupt that does not cause a task switch will clear NT. NT may also be set or cleared by POPF or IRET instructions.

The task state segment is marked busy by changing the descriptor type field from Type 1 to Type 3. Use of a selector that references a busy task state segment causes Exception 13.

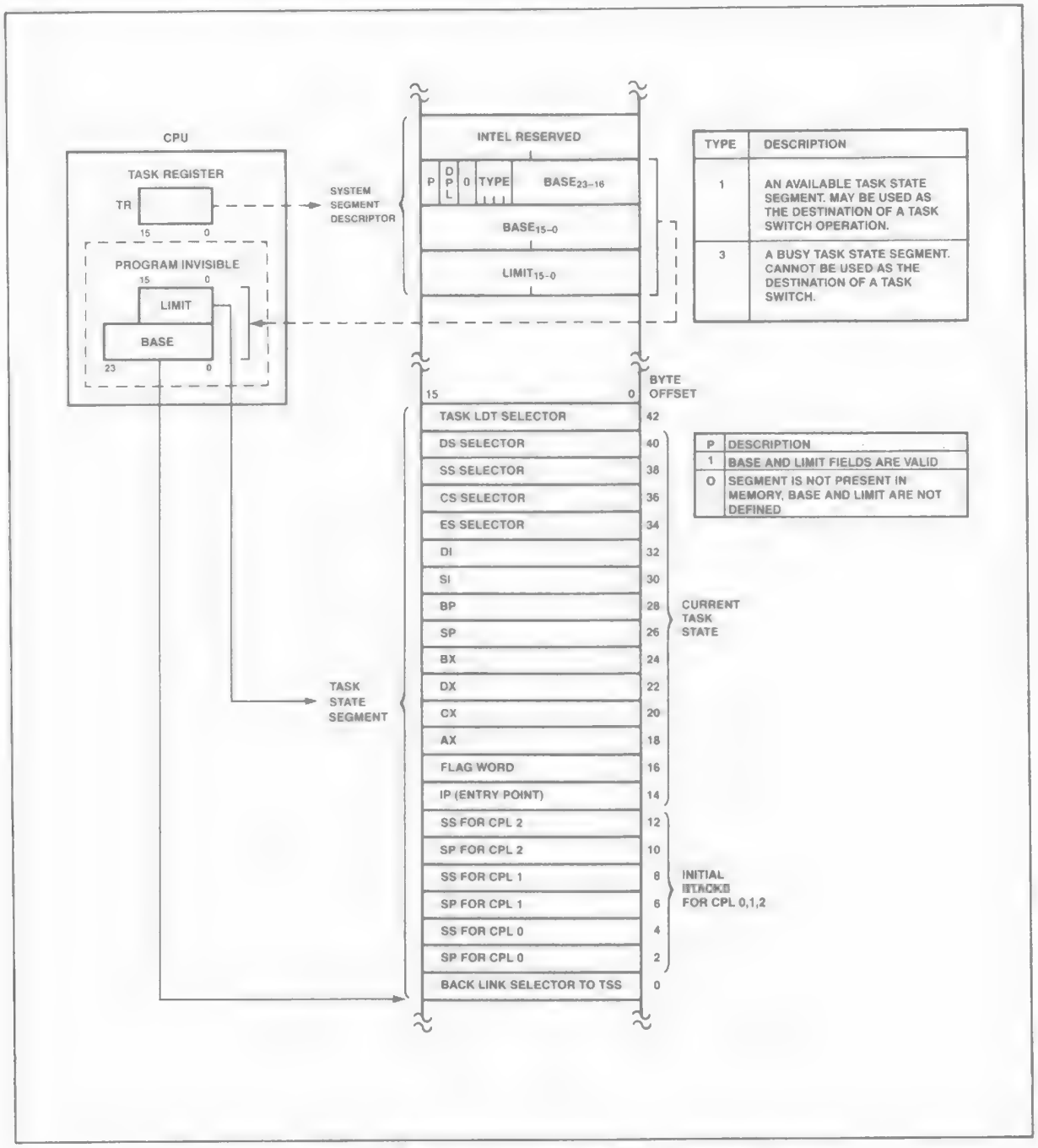
PROCESSOR EXTENSION CONTEXT SWITCHING

The context of a processor extension (such as the 80287 numerics processor) is not changed by the task switch operation. A processor extension context need only be changed when a different task attempts to use the processor extension (which still contains the context of a previous task). The 80286 detects the first use of a processor extension after a task switch by causing the processor extension not present exception (7). The interrupt handler may then decide whether a context change is necessary.

Whenever the 80286 switches tasks, it sets the Task Switched (TS) bit of the MSW. TS indicates that a processor extension context may belong to a different task than the current one. The processor extension not present exception (7) will occur when attempting to execute an ESC or WAIT instruction if TS = 1 and a processor extension is present (MP = 1 in MSW).

POINTER TESTING INSTRUCTIONS

The iAPX 80286 provides several instructions to speed pointer testing and consistency checks for maintaining system integrity (see Table 15). These instructions use the memory management hardware to verify that a selector value refers to an appropriate segment without risking an exception. A condition flag indicates whether use of the selector or segment will cause an exception.



TYPE	DESCRIPTION
1	AN AVAILABLE TASK STATE SEGMENT. MAY BE USED AS THE DESTINATION OF A TASK SWITCH OPERATION.
3	A BUSY TASK STATE SEGMENT. CANNOT BE USED AS THE DESTINATION OF A TASK SWITCH.

P	DESCRIPTION
1	BASE AND LIMIT FIELDS ARE VALID
0	SEGMENT IS NOT PRESENT IN MEMORY, BASE AND LIMIT ARE NOT DEFINED

Figure 20. Task State Segment and TSS Registers

Table 15. Pointer Test Instructions

Instruction	Operands	Function
ARPL	Selector, Register	Adjust Requested Privilege Level: adjusts the RPL of the selector to the numeric maximum of current selector RPL value and the RPL value in the register. Set zero flag if selector RPL was changed.
VERR	Selector	VERify for Read: sets the zero flag if the segment referred to by the selector can be read.
VERW	Selector	VERify for Write: sets the zero flag if the segment referred to by the selector can be written.
LSL	Register, Selector	Load Segment Limit: reads the segment limit into the register if privilege rules and descriptor type allow. Set zero flag if successful.
LAR	Register, Selector	Load Access Rights: reads the descriptor access rights byte into the register if privilege rules allow. Set zero flag if successful.

DOUBLE FAULT AND SHUTDOWN

If two separate exceptions are detected during a single instruction execution, the 80286 performs the double fault exception (8). If an exception occurs during processing of the double fault exception, the 82086 will enter shutdown. During shutdown no further instructions or exceptions are processed. Either NMI (CPU remains in protected mode) or RESET (CPU exits protected mode) can force the 80286 out of shutdown. Shutdown is externally signalled via a HALT bus operation with A_1 HIGH.

PROTECTED MODE INITIALIZATION

The 80286 initially executes in real address mode after RESET. To allow initialization code to be placed at the top of physical memory, A_{23-20} will be HIGH when the 80286 performs memory references relative to the CS register, until CS is changed. A_{23-20} will be zero for references to the DS, ES, or SS segments. Changing CS in real address mode will force A_{23}–A_{20} LOW whenever using CS thereafter. The initial CS:IP value of F000:FFF0 provides 64K bytes of code space for initialization code without changing CS.

Before placing the 80286 into protected mode, several registers must be initialized. The GDT and IDT base registers must refer to a valid GDT and IDT. After executing the LMSW instruction to set PE, the 80286 must immediately execute an intra-segment JMP instruction to clear the instruction queue of instructions decoded in real address mode.

To force the 80286 CPU registers to match the initial protected mode state assumed by software, execute a JMP instruction with a selector referring to the initial TSS used in the system. This will load the task register, local descriptor table register, segment registers and initial general register state. The TR should point at a valid TSS since a task switch operation involves saving the current task state.

SYSTEM INTERFACE

The 80286 system interface appears in two forms: a local bus and a system bus. The local bus consists of address, data, status, and control signals at the pins of the CPU. A system bus is any buffered version of the local bus. A system bus may also differ from the local bus in terms of coding of status and control lines and/or timing and loading of signals. The iAPX 286 family includes several devices to generate standard system buses such as the IEEE 796 standard Multibus™.

Bus Interface Signals and Timing

The iAPX 286 microsystem local bus interfaces the 80286 to local memory and I/O components. The interface has 24 address lines, 16 data lines, and 8 status and control signals.

The 80286 CPU, 82284 clock generator, 82288 bus controller, 82289 bus arbiter, 8286/7 transceivers, and 8282/3 latches provide a buffered and decoded system bus interface. The 82284 generates the system clock and synchronizes $\overline{\text{READY}}$ and RESET. The 82288 converts bus operation status encoded by the 80286 into command and bus control signals. The 82289 bus arbiter generates multibus bus arbitration signals. These components can provide the timing and electrical power drive levels required for most system bus interfaces including the multibus.

Physical Memory and I/O Interface

A maximum of 16 megabytes of physical memory can be addressed in protected mode. One megabyte can be addressed in real address mode. Memory is accessible as bytes or words. Words consist of any two consecutive bytes addressed with the least significant byte stored in the lowest address.

Byte transfers occur on either half of the 16-bit local data bus. Even bytes are accessed over D_{7-0} while odd bytes are transferred over D_{15-8}. Even-addressed words are transferred over D_{15-0} in one bus cycle, while odd-addressed words require two bus operations. The first transfers data on D_{15-8}, and the second transfers data on D_{7-0}. Both byte data transfers occur automatically, transparent to software.

Two bus signals, A_0 and $\overline{\text{BHE}}$, control transfers over the lower and upper halves of the data bus. Even address

byte transfers are indicated by A_0 LOW and $\overline{BHE}$ HIGH. Odd address byte transfers are indicated by A_0 HIGH and $\overline{BHE}$ LOW. Both A_0 and $\overline{BHE}$ are LOW for even address word transfers.

The I/O address space contains 64K addresses in both modes. The I/O space is accessible as either bytes or words, as is memory. Byte wide peripheral devices may be attached to either the upper or lower byte of the data bus. Byte-wide I/O devices attached to the upper data byte (D_{15-8}) are accessed with odd I/O addresses. Devices on the lower data byte are accessed with even I/O addresses. An interrupt controller such as Intel's 8259A must be connected to the lower data byte (D_{7-0}) for proper return of the interrupt vector.

Bus Operation

The 80286 uses a double frequency system clock (CLK input) to control bus timing. All signals on the local bus are measured relative to the system CLK input. The CPU divides the system clock by 2 to produce the internal processor clock, which determines bus state. Each processor clock is composed of two system clock cycles named phase 1 and phase 2. The 82284 clock generator output (PCLK) identifies the next phase of the processor clock. (See Figure 21.)

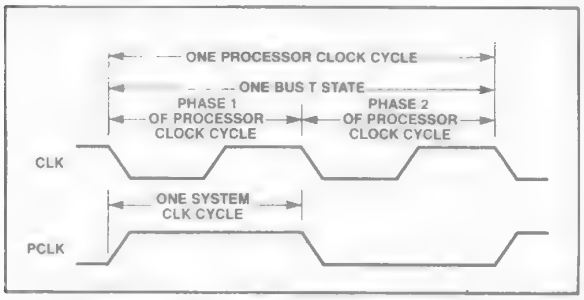


Figure 21. System and Processor Clock Relationships

Six types of bus operations are supported; memory read, memory write, I/O read, I/O write, interrupt acknowledge, and halt/shutdown. Data can be transferred at a maximum rate of one word per two processor clock cycles.

The iAPX 286 bus has three basic states: idle (T_i), send status (T_s), and perform command (T_c). The 80286 CPU also has a fourth local bus state called hold (T_h). T_h indicates that the 80286 has surrendered control of the local bus to another bus master in response to a HOLD request.

Each bus state is one processor clock long. Figure 22 shows the four 80286 local bus states and allowed transitions.

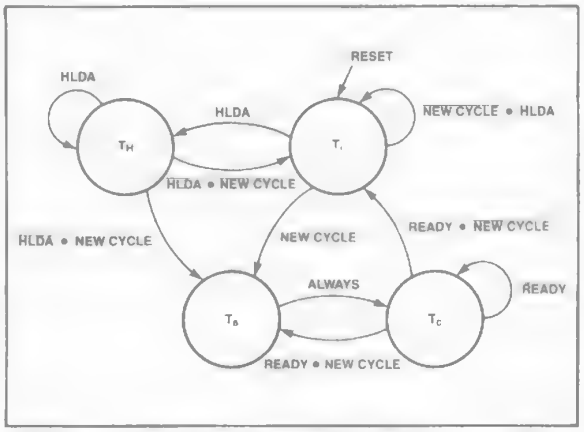


Figure 22. 80286 Bus States

Bus States

The idle (T_i) state indicates that no data transfers are in progress or requested. The first active state, T_s is signalled by either status line $\overline{S1}$ or $\overline{S0}$ going LOW also identifying phase 1 of the processor clock. During T_s, the command encoding, the address, and data (for a write operation) are available on the 80286 output pins. The 82288 bus controller decodes the status signals and generates Multibus compatible read/write command and local transceiver control signals.

After T_s, the perform command (T_c) state is entered. Memory or I/O devices respond to the bus operation during T_c, either transferring read data to the CPU or accepting write data. T_c states may be repeated as often as necessary to assure sufficient time for the memory or I/O device to respond. The $\overline{READY}$ signal determines whether T_c is repeated.

During hold (T_h), the 80286 will float all address, data, and status output pins enabling another bus master to use the local bus. The 80286 HOLD input signal is used to place the 80286 into the T_h state. The 80286 HLDA output signal indicates that the CPU has entered T_h.

Pipelined Addressing

The 80286 uses a local bus interface with pipelined timing to allow as much time as possible for data access. Pipelined timing allows bus operations to be performed in two processor cycles, while allowing each individual bus operation to last for three processor cycles.

The timing of the address outputs is pipelined such that the address of the next bus operation becomes available during the current bus operation. Or in other words, the first clock of the next bus operation is overlapped with the last clock of the current bus operation. Therefore, address decode and routing logic can operate in ad-

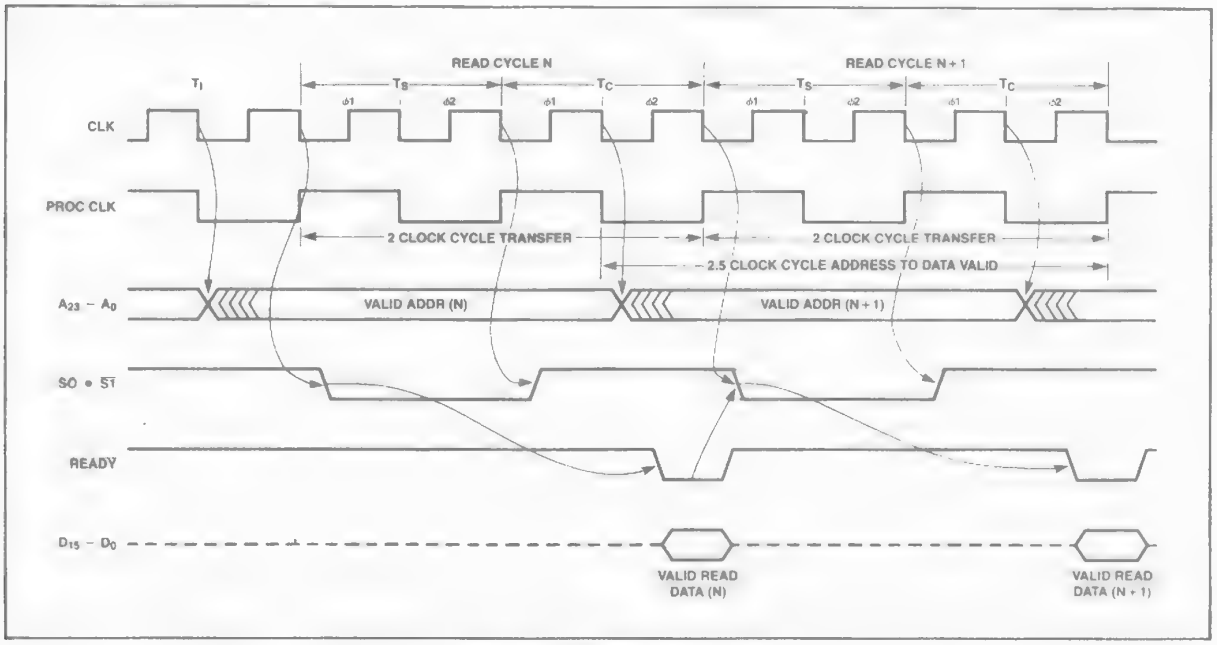


Figure 23. Basic Bus Cycle

vance of the next bus operation. External address latches may hold the address stable for the entire bus operation, and provide additional AC and DC buffering.

The 80286 does not maintain the address of the current bus operation during all T_C states. Instead, the address for the next bus operation may be emitted during phase 2 of any T_C. The address remains valid during phase 1 of the first T_C to guarantee hold time, relative to ALE, for the address latch inputs.

Bus Control Signals

The 82288 bus controller provides control signals; address latch enable (ALE), Read/Write commands, data transmit/receive (DT/$\overline{R}$), and data enable (DEN) that control the address latches, data transceivers, write enable, and output enable for memory and I/O systems.

The Address Latch Enable (ALE) output determines when the address may be latched. ALE provides at least one system CLK period of address hold time from the end of the previous bus operation until the address for the next bus operation appears at the latch outputs. This address hold time is required to support Multibus® and common memory systems.

The data bus transceivers are controlled by 82288 outputs Data Enable (DEN) and Data Transmit/Receive (DT/$\overline{R}$). DEN enables the data transceivers; while DT/$\overline{R}$ controls transceiver direction. DEN and DT/$\overline{R}$ are timed to prevent bus contention between the bus master, data bus transceivers, and system data bus tranceivers.

Command Timing Controls

Two system timing customization options, command extension and command delay, are provided on the iAPX 286 local bus.

Command extension allows additional time for external devices to respond to a command and is analogous to inserting wait states on the 8086. External logic can control the duration of any bus operation such that the operation is only as long as necessary. The $\overline{READY}$ input signal can extend any bus operation for as long as necessary.

Command delay allows an increase of address or write data setup time to system bus command active for any bus operation by delaying when the system bus command becomes active. Command delay is controlled by the 82288 CMDLY input. After T_S, the bus controller samples CMDLY at each failing edge of CLK. If CMDLY is HIGH, the 82288 will not activate the command signal. When CMDLY is LOW, the 82288 will activate the command signal. After the command becomes active, the CMDLY input is not sampled.

When a command is delayed, the available response time from command active to return read data or accept write data is less. To customize system bus timing, an address decoder can determine which bus operations require delaying the command. The CMDLY input does not affect the timing of ALE, DEN, or DT/$\overline{R}$.

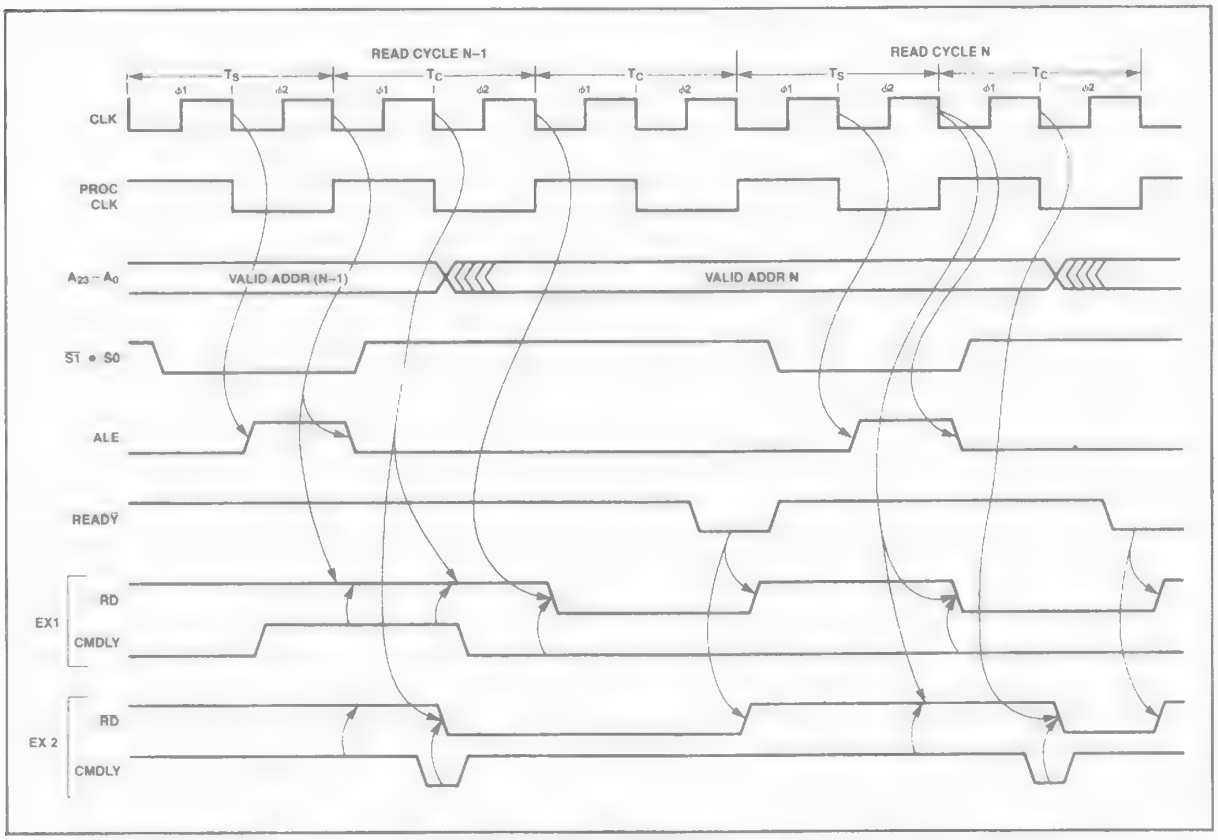


Figure 24. CMDLY Controls and Leading Edge of the Command

Figure 24 illustrates four uses of CMDLY. Example 1 shows delaying the read command two system CLKs for cycle N-1 and no delay for cycle N, and example 2 shows delaying the read command one system CLK for cycle N-1 and one system CLK delay for cycle N.

Bus Cycle Termination

At maximum transfer rates, the iAPX 286 bus alternates between the status and command states. The bus status signals become inactive after T_S so that they may correctly signal the start of the next bus operation after the completion of the current cycle. No external indication of T_C exists on the iAPX 286 local bus. The bus master and bus controller enter T_C directly after T_S and continue executing T_C cycles until terminated by $\overline{READY}$.

$\overline{READY}$ Operation

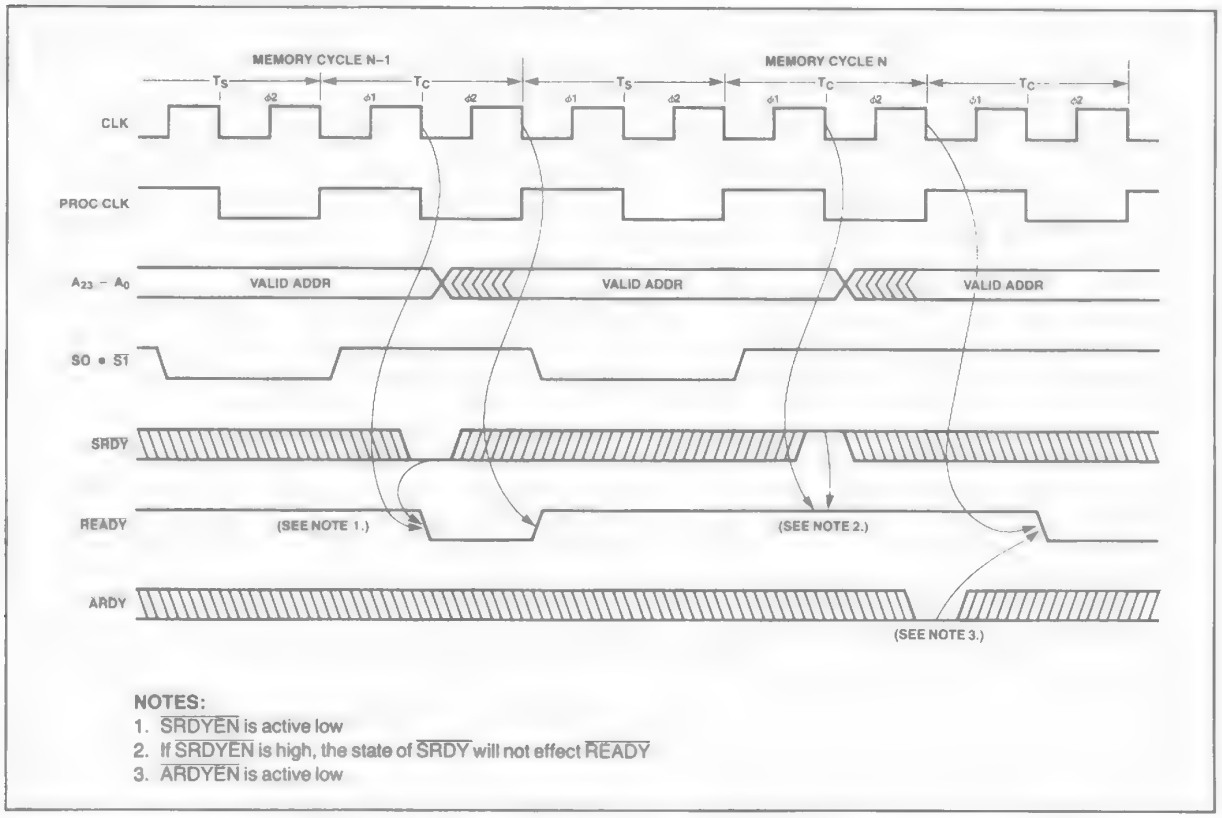
The current bus master and 82288 bus controller terminate each bus operation simultaneously to achieve maximum bus bandwidth. Both are informed in advance by $\overline{READY}$ active which identifies the last T_C cycle of the current bus operation. The bus master and bus controller must see the same sense of the $\overline{READY}$ signal, thereby requiring $\overline{READY}$ be synchronous to the system clock.

Synchronous Ready

The 82284 clock generator provides $\overline{READY}$ synchronization from both synchronous and asynchronous sources (see Figure 25). The synchronous ready input ($\overline{SRDY}$) of the clock generator is sampled with the falling edge of CLK at the end of phase 1 of each T_C. The state of $\overline{SRDY}$ is then broadcast to the bus master and bus controller via the $\overline{READY}$ output line.

Asynchronous Ready

Many systems have devices or subsystems that are asynchronous to the system clock. As a result, their ready outputs cannot be guaranteed to meet the 82284 $\overline{SRDY}$ setup and hold time requirements. The 82284 asynchronous ready input ($\overline{ARDY}$) is designed to accept such signals. The $\overline{ARDY}$ input is sampled at the beginning of each T_C cycle by 82284 synchronization logic. This provides a system CLK cycle time to resolve its value before broadcasting it to the bus master and bus controller.



NOTES:
1. $\overline{SRDYEN}$ is active low
2. If $\overline{SRDYEN}$ is high, the state of $\overline{SRDY}$ will not effect $\overline{READY}$
3. $\overline{ARDYEN}$ is active low

Figure 25. Synchronous and Asynchronous Ready

Each ready input of the 82284 has an enable pin ($\overline{SRDYEN}$ and $\overline{ARDYEN}$) to select whether the current bus operation will be terminated by the synchronous or asynchronous ready. Either of the ready inputs may terminate a bus operation. These enable inputs are active low and have the same timing as their respective ready inputs. Address decode logic usually selects whether the current bus operation should be terminated by $\overline{ARDY}$ or $\overline{SRDY}$.

Data Bus Control

Figures 26, 27, and 28 show how the DT/$\overline{R}$, DEN, data bus, and address signals operate for different combinations of read, write, and idle bus operations. DT/$\overline{R}$ goes active (LOW) for a read operaton. DT/$\overline{R}$ remains HIGH before, during, and between write operations.

The data bus is driven with write data during the second phase of T_S. The delay in write data timing allows the read data drivers, from a previous read cycle, sufficient time to enter 3-state OFF before the 80286 CPU begins driving the local data bus for write operations. Write data will always remain valid for one system clock past the last T_C to provide sufficient hold time for Multibus or other similar memory or I/O systems. During write-read or write-idle sequences the data bus enters 3-state OFF during the second phase of the processor cycle after the last T_C. In a write-write sequence the data bus does not enter 3-state OFF between T_C and T_S.

Bus Usage

The 80286 local bus may be used for several functions: instruction data transfers, data transfers by other bus masters, instruction fetching, processor extension data transfers, interrupt acknowledge, and halt/shutdown. This section describes local bus activities which have special signals or requirements.

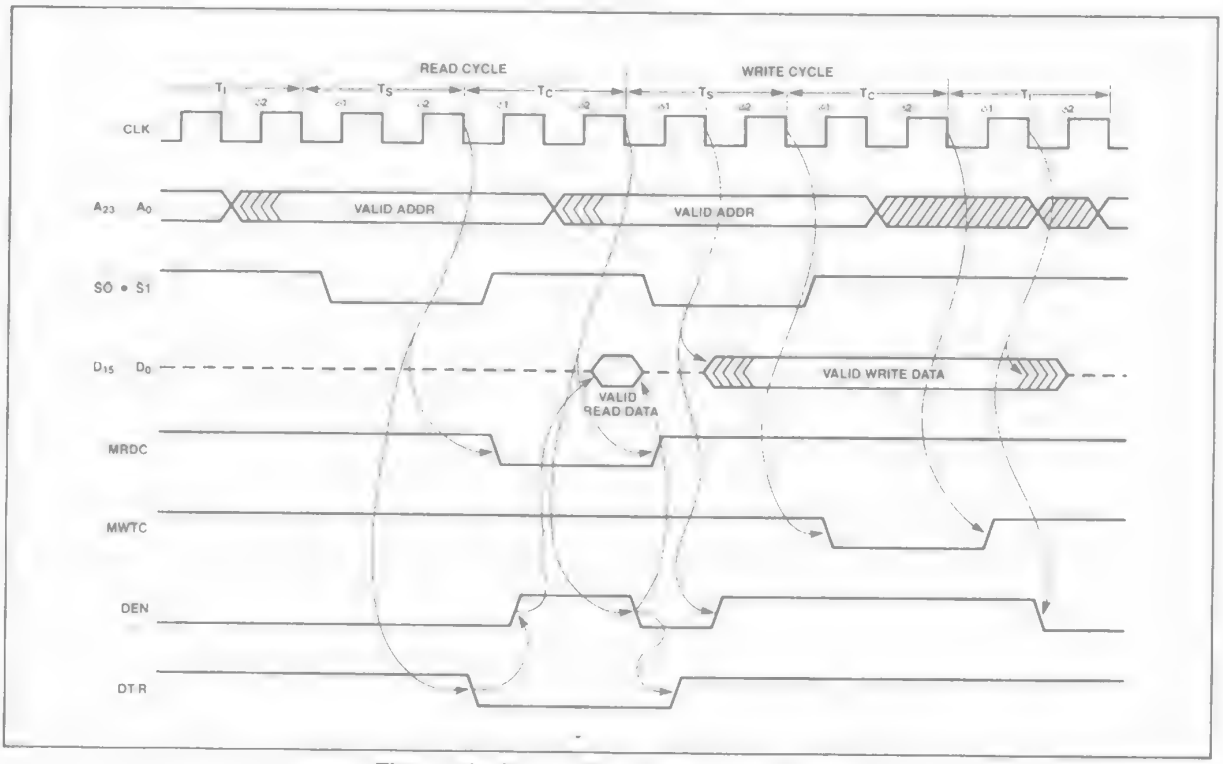


Figure 26. Back to Back Read-Write Cycles

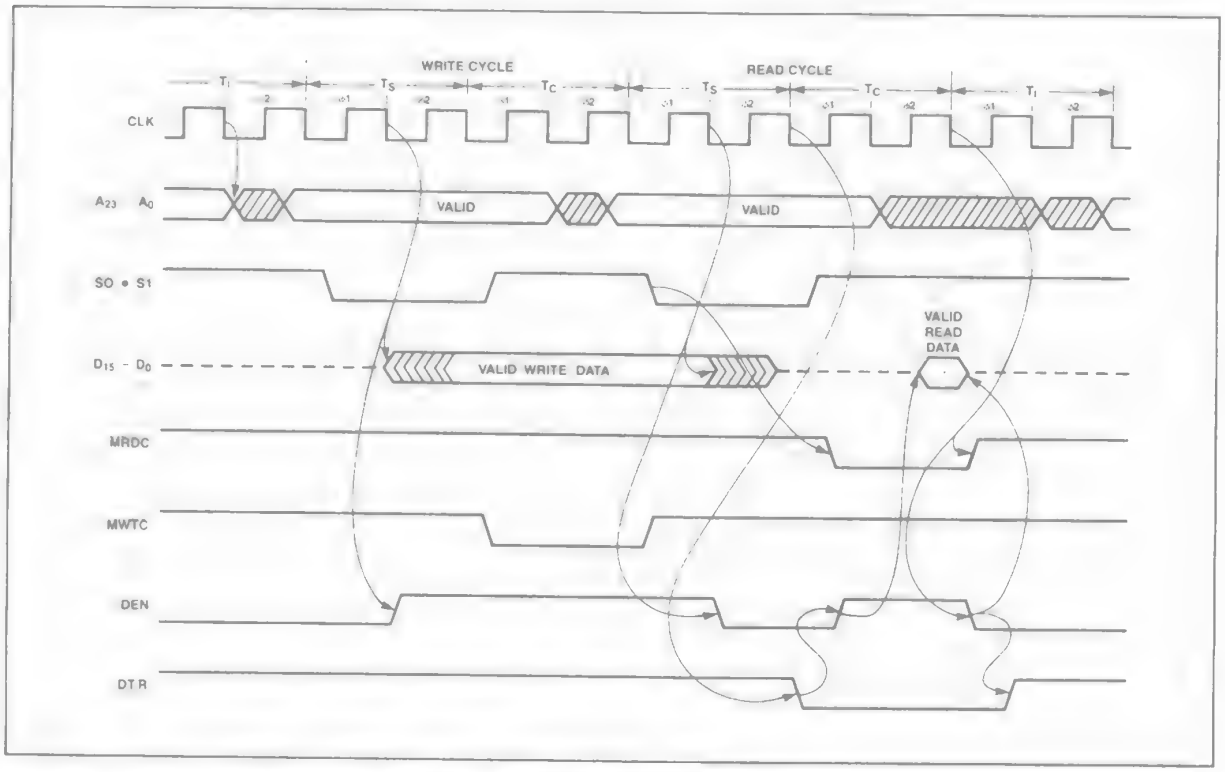


Figure 27. Back to Back Write-Read Cycles

AFN-02060B

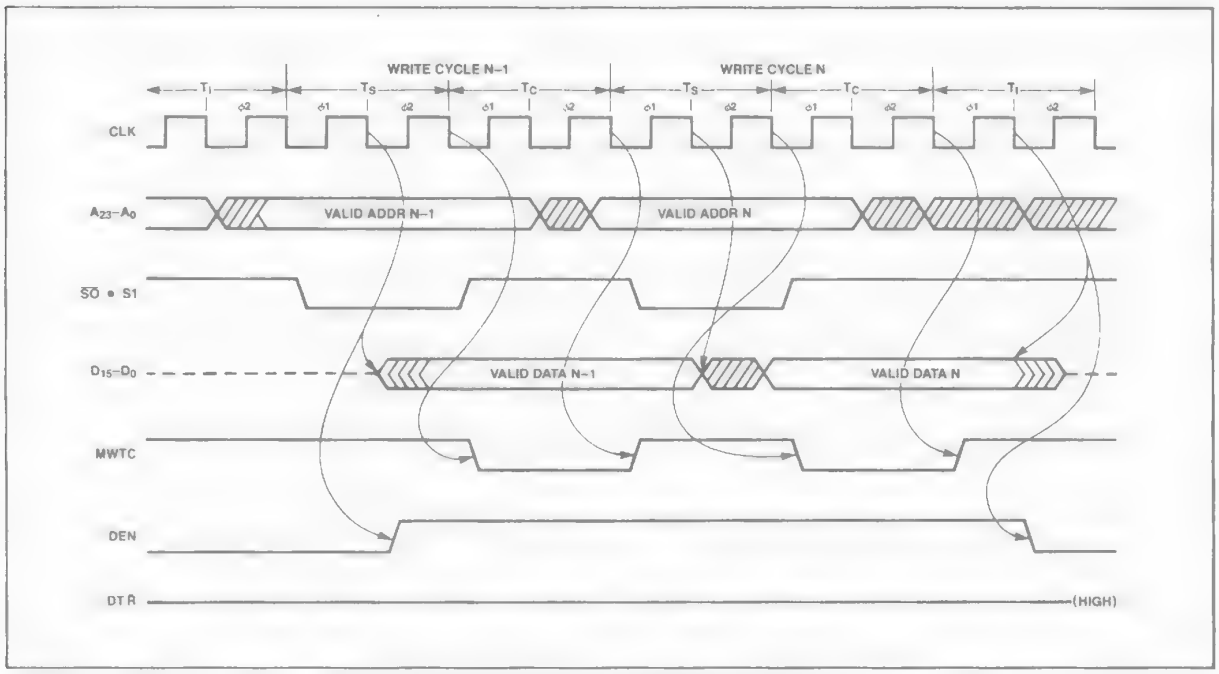


Figure 28. Back to Back Write-Write Cycles

HOLD and HLDA

HOLD and HLDA allow another bus master to gain control of the local bus by placing the 80286 bus into the T_h state. The sequence of events required to pass control between the 80286 and another local bus master are shown in Figure 29.

In this example, the 80286 is initially in the T_h state as signaled by HLDA being active. Upon leaving T_h, as signaled by HLDA going inactive, a write operation is started. During the write operation another local bus master requests the local bus from the 80286 as shown by the HOLD signal. After completing the write operation, the 80286 performs one T_i bus cycle, to guarantee write data hold time, then enters T_h as signaled by HLDA going active.

The CMDLY signal and $\overline{ARDY}$ ready are used to start and stop the write bus command, respectively. Note that $\overline{SRDY}$ must be inactive or disabled by $\overline{SRDYEN}$ to guarantee $\overline{ARDY}$ will terminate the cycle.

Instruction Fetching

The 80286 Bus Unit (BU) will fetch instructions ahead of the current instruction being executed. This activity is called prefetching. It occurs when the local bus would otherwise be idle and obeys the following rules:

A prefetch bus operation starts when at least two bytes of the 6-byte prefetch queue are empty.

The prefetcher normally performs word prefetches independent of the byte alignment of the code segment base in physical memory.

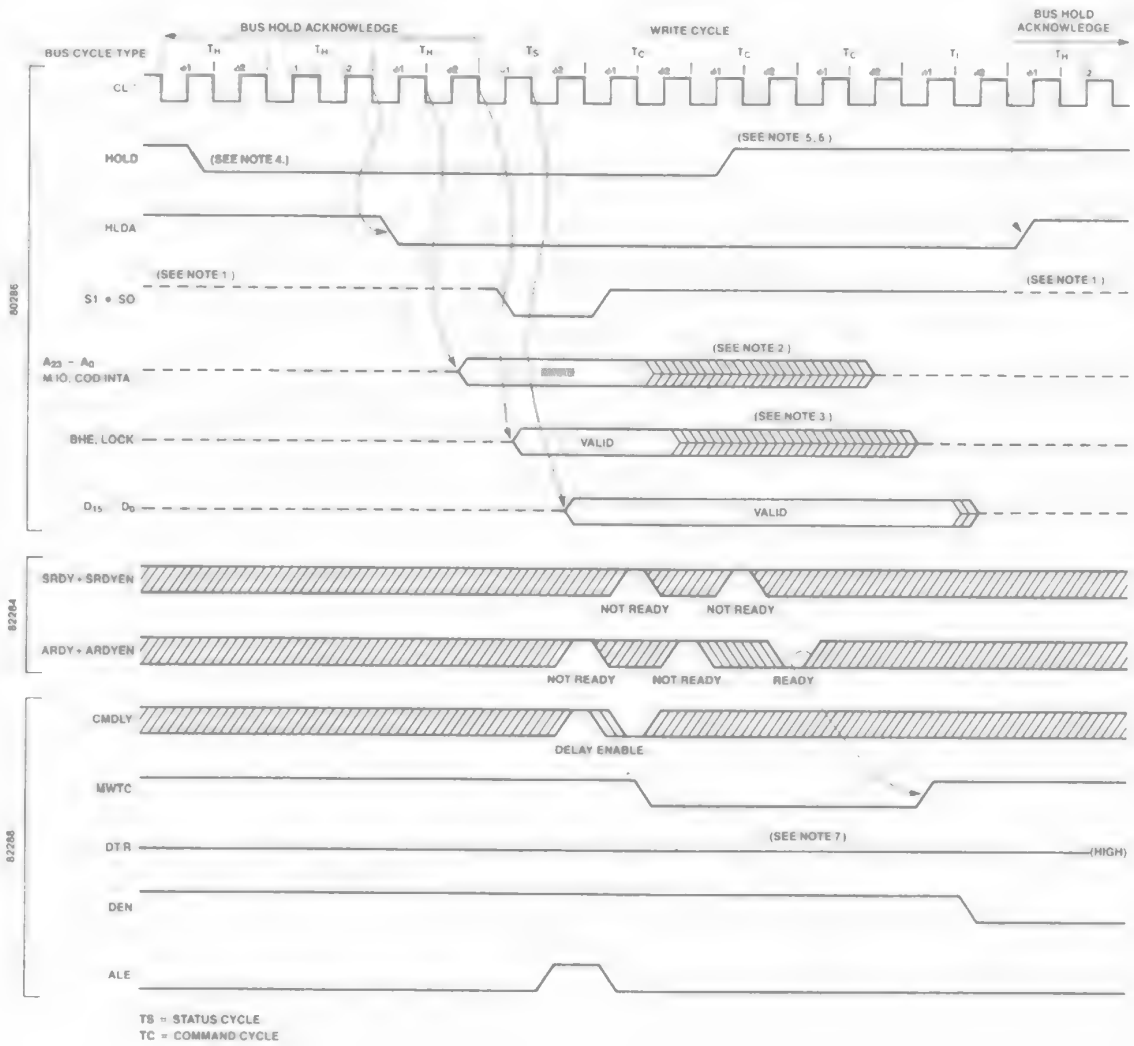
The prefetcher will perform only a byte code fetch operation for control transfers to an instruction beginning on a numerically odd physical address.

Prefetching stops whenever a control transfer or HLT instruction is decoded by the IU and placed into the instruction queue.

In real address mode, the prefetcher may fetch up to 5 bytes beyond the last control transfer or HLT instruction in a code segment.

In protected mode, the prefetcher will never cause a segment overrun exception. The prefetcher stops at the last physical memory word of the code segment. Exception 13 will occur if the program attempts to execute beyond the last full instruction in the code segment.

If the last byte of a code segment appears on an even physical memory address, the prefetcher will read the next physical byte of memory (perform a word code fetch). The value of this byte is ignored and any attempt to execute it causes exception 13.



NOTES:

1. Status lines are not driven by 80286, yet remain high due to pullup resistors in 82288 and 82289 during HOLD state.
2. Address, M/$\overline{IO}$ and COD/$\overline{INTA}$ may start floating during any TC depending on when internal 80286 bus arbiter decides to release bus to external HOLD. The float starts in $\phi 2$ of TC.
3. $\overline{BHE}$ and $\overline{LOCK}$ may start floating after the end of any TC depending on when internal 80286 bus arbiter decides to release bus to external HOLD.
4. The minimum HOLD ↓ to HLDA ↓ time is shown. Maximus is one T_H longer.
5. The earliest HOLD ↑ time is shown which will always allow a subsequent memory cycle if pending.
6. The minimum HOLD ↑ to HLDA ↑ time is shown. Maximum is a function of the instruction, type of bus cycle and other machine status (i.e., Interrupts, Waits, Lock, etc.)
7. Asynchronous ready allows termination of the cycle. Synchronous ready does not signal ready in this example. Synchronous ready state is ignored after ready is signaled via the asynchronous input.

Figure 29. Multibus Write Terminated by Asynchronous Ready

Processor Extension Transfers

The processor extension interface uses I/O port addresses 00F8(H), 00FA(H), and 00FC(H) which are part of the I/O port address range reserved by Intel. An ESC instruction with EM = 0 and TS = 0 will perform I/O bus operations to one or more of these I/O port addresses independent of the value of IOPL and CPL.

ESC instructions with memory references enable the CPU to accept PEREQ inputs for processor extension operand transfers. The CPU will determine the operand starting address and read/write status of the instruction. For each operand transfer, two or three bus operations are performed, one word transfer with I/O port address 00FA(H) and one or two bus operations with memory. Three bus operations are required for each word operand aligned on an odd byte address.

Interrupt Acknowledge Sequence

Figure 30 illustrates an interrupt acknowledge sequence performed by the 80286 in response to an INTR input. An interrupt acknowledge sequence consists of two INTA bus operations. The first allows a master 8259A Programmable Interrupt Controller (PIC) to determine which if any of its slaves should return the interrupt vector. An eight bit vector is read by the 80286 during the second INTA bus operation to select an interrupt handler routine from the interrupt table.

The Master Cascade Enable (MCE) signal of the 82288 is used to enable the cascade address drivers, during INTA bus operations (See Figure 30), onto the local address bus for distribution to slave interrupt controllers via the system address bus. The 80286 emits the $\overline{LOCK}$ signal (active LOW) during T_s of the first INTA bus operation. A local bus "hold" request will not be honored until the end of the second INTA bus operation.

Three idle processor clocks are provided by the 80286 between INTA bus operations to allow for the minimum INTA to INTA time and CAS (cascade address) out delay of the 8259A. The second INTA bus operation must always have at least one extra T_c state added via logic controlling $\overline{READY}$. A_{23}–A_0 are in 3-state OFF until after the first T_c state of the second INTA bus operation. This prevents bus contention between the cascade address drivers and CPU address drivers. The extra T_c state allows time for the 80286 to resume driving the address lines for subsequent bus operations.

Local Bus Usage Priorities

The 80286 local bus is shared among several internal units and external HOLD requests. In case of simultaneous requests, their relative priorities are:

(Highest) Any transfers which assert $\overline{LOCK}$ either explicitly (via the LOCK instruction prefix) or implicitly (i.e. segment descriptor access, interrupt acknowledge sequence, or an XCHG with memory).

The second of the two byte bus operations required for an odd aligned word operand.

Local bus request via HOLD input.

Processor extension data operand transfer via PEREQ input.

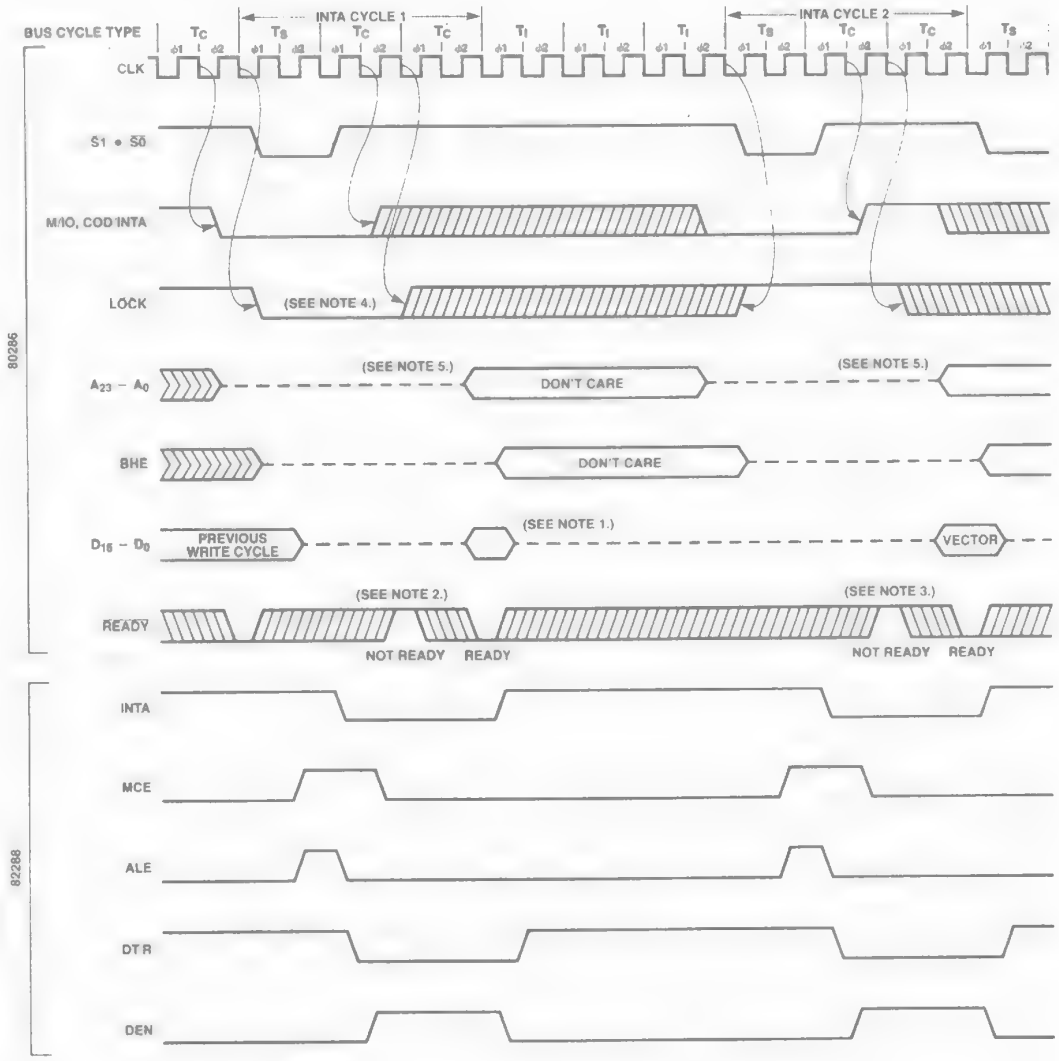
Data transfer performed by EU as part of an instruction.

(Lowest) An instruction prefetch request from BU. The EU will inhibit prefetching two processor clocks in advance of any data transfers to minimize waiting by EU for a prefetch to finish.

Halt or Shutdown Cycles

The 80286 externally indicates halt or shutdown conditions as a bus operation. These conditions occur due to a HLT instruction or multiple protection exceptions while attempting to execute one instruction. A halt or shutdown bus operation is signalled when $\overline{S1}$, $\overline{S0}$ and COD/$\overline{INTA}$ are LOW and M/$\overline{IO}$ is HIGH. A_1 HIGH indicates halt, and A_1 LOW indicates shutdown. The 82288 bus controller does not issue ALE, nor is $\overline{READY}$ required to terminate a halt or shutdown bus operation.

During halt or shutdown, the 80286 may service PEREQ or HOLD requests. A processor extension segment overrun exception during shutdown will inhibit further service of PEREQ. Either NMI or RESET will force the 80286 out of either halt or shutdown. An INTR, if interrupts are enabled, or a processor extension segment overrun exception will also force the 80286 out of halt.



NOTES:

1. Data is ignored.
2. First INTA cycle should have at least one wait state inserted to meet 8259A minimum INTA pulse width.
3. Second INTA cycle must have at least one wait state inserted since the CPU will not drive A_{23} – A_0, $\overline{BHE}$, and $\overline{LOCK}$ until after the first TC state.

   The CPU imposed one/clock delay prevents bus contention between cascade address buffer being disabled by MCE ↓ and address outputs.

   Without the wait state, the 80286 address will not be valid for a memory cycle started immediately after the second INTA cycle. The 8259A also requires one wait state for minimum INTA pulse width.
4. $\overline{LOCK}$ is active for the first INTA cycle to prevent the 82289 from releasing the bus between INTA cycles in a multi-master system.
5. A_{23} – A_0 exits 3-state OFF during $\phi 2$ of the second T_C in the INTA cycle.

Figure 30. Interrupt Acknowledge Sequence

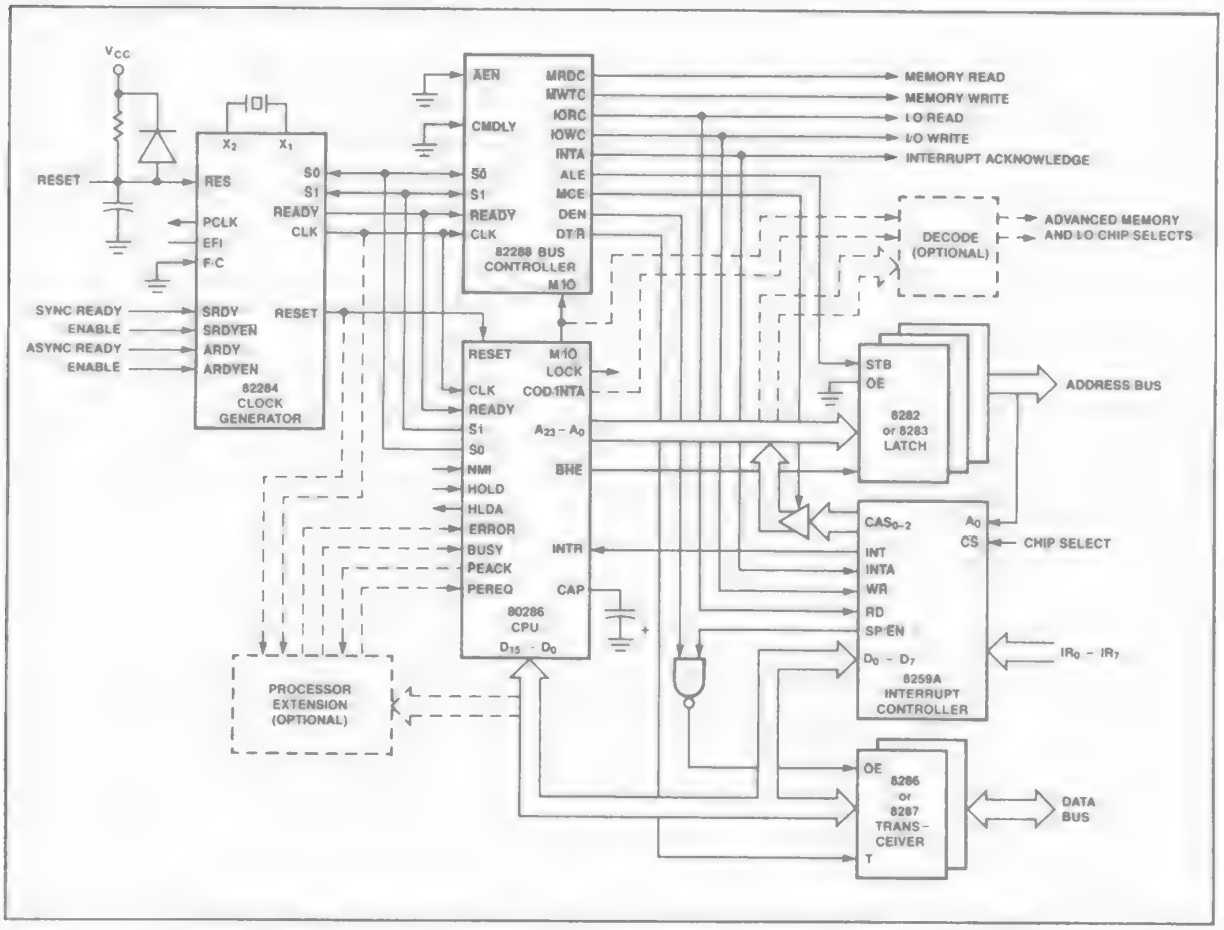


Figure 31. Basic iAPX 286 System Configuration

SYSTEM CONFIGURATIONS

The versatile bus structure of the iAPX 286 microsystem, with a full complement of support chips, allows flexible configuration of a wide range of systems. The basic configuration, shown in Figure 31, is similar to an iAPX 86 maximum mode system. It includes the CPU plus an 8259A interrupt controller, 82284 clock generator, and the 82288 Bus Controller. The iAPX 86 latches (8282 and 8283) and transceivers (8286 and 8287) may be used in an iAPX 286 microsystem.

As indicated by the dashed lines in Figure 31, the ability to add processor extensions is an integral feature of iAPX 286 microsystems. The processor extension interface allows external hardware to perform special functions and transfer data concurrent with CPU execution of other instructions. Full system integrity is maintained because the 80286 supervises all data transfers and instruction execution for the processor extension.

The iAPX 286/20 numeric data processor which includes the 80287 numeric processor extension (NPX) uses this interface. The iAPX 286/20 has all the instructions and data types of an iAPX 86/20 or iAPX 88/20. The 80287 NPX can perform numeric calculations and data transfers concurrently with CPU program execution. Numerics code and data have the same integrity as all other information protected by the iAPX 286 protection mechanism.

The 80286 can overlap chip select decoding and address propagation during the data transfer for the previous bus operation. This information is latched into the 8282/3's by ALE during the middle of a T_s cycle. The latched chip select and address information remains stable during the bus operation while the next cycles address is being decoded and propagated into the system. Decode logic can be implemented with a high speed bipolar PROM.

The optional decode logic shown in Figure 31 takes advantage of the overlap between address and data of the 80286 bus cycle to generate advanced memory and IO-select signals. This minimizes system performance

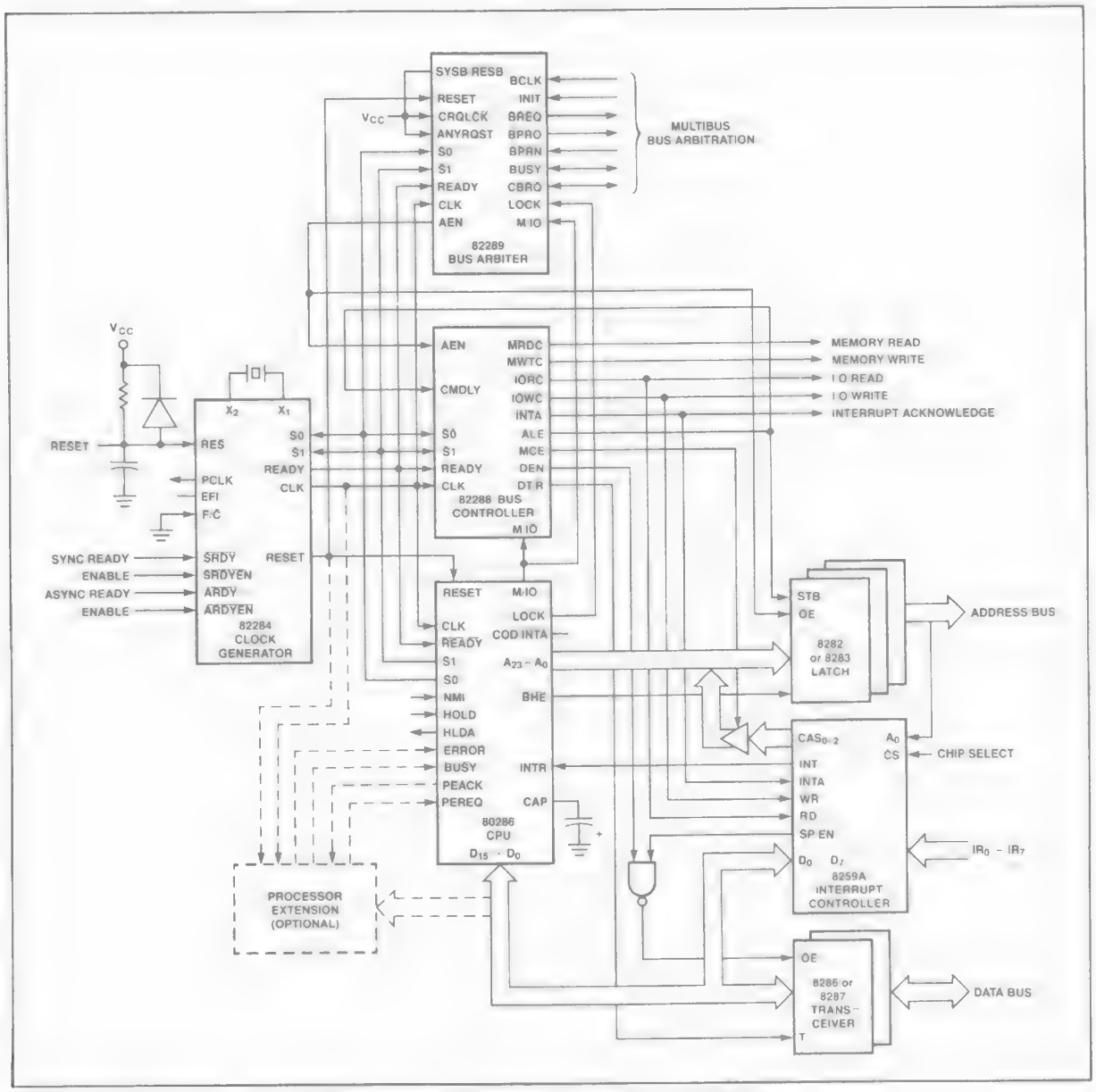


Figure 32. Multibus System Bus Interface

degradation caused by address propogation and decode delays. In addition to selecting memory and I/O, the advanced selects may be used with configurations supporting local and system buses to enable the appropriate bus interface for each bus cycle. The COD/$\overline{\text{INTA}}$ and M/$\overline{\text{IO}}$ signals are applied to the decode logic to distinguish between interrupt, I/O, code and data bus cycles.

By adding the 82289 bus arbiter chip the 80286 provides a Multibus system bus interface as shown in Figure 32. The ALE output of the 82288 for the Multibus bus is connected to its CMDLY input to delay the start of commands one system CLK as required to meet Multibus address and write data setup times. This arrangement will add at least one extra T_C state to each bus operation which uses the Multibus.

A second 82288 bus controller and additional latches and transceivers could be added to the local bus of Figure 32. This configuration allows the 80286 to support an on-board bus for local memory and peripherals, and the Multibus for system bus interfacing.

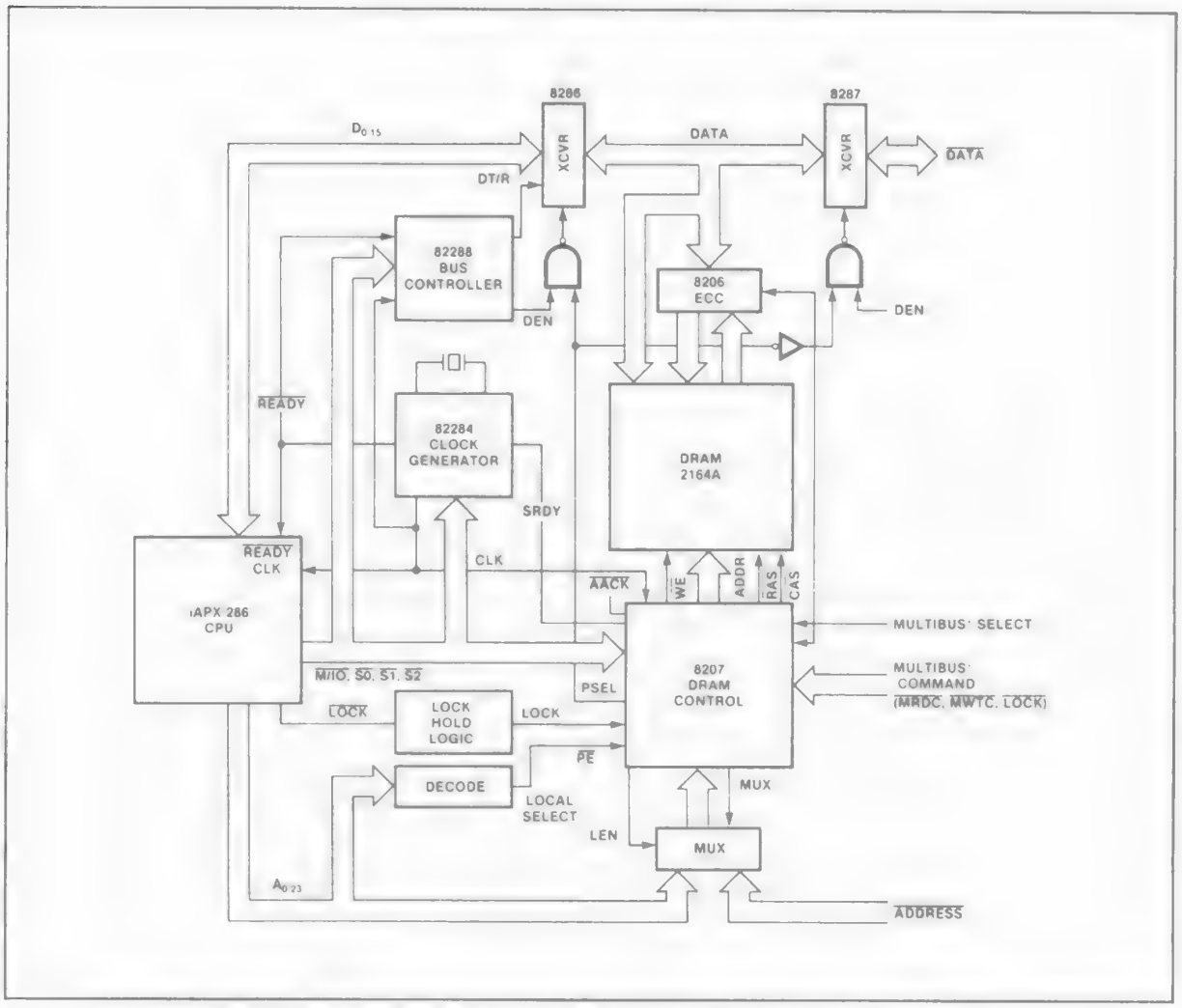


Figure 33. iAPX 286 System Configuration with Dual-Ported Memory

Figure 33 shows the addition of dual ported dynamic memory between the Multibus system bus and the iAPX 286 local bus. The dual port interface is provided by the 8207 Dual Port DRAM Controller. The 8207 runs synchronously with the CPU to maximize throughput for local memory references. It also arbitrates between requests from the local and system buses and performs functions such as refresh, initialization of RAM, and read/modify/write cycles. The 8207 combined with the 8206 Error Checking and Correction memory controller provide for single bit error correction. The dual-ported memory can be combined with a standard Multibus system bus interface to maximize performance and protection in multiprocessor system configurations.

PACKAGE

The 80286 is packaged in a 68-pin, leadless JEDEC type A hermetic chip carrier. Figure 34 illustrates the package, and Figure 2 shows the pinout.

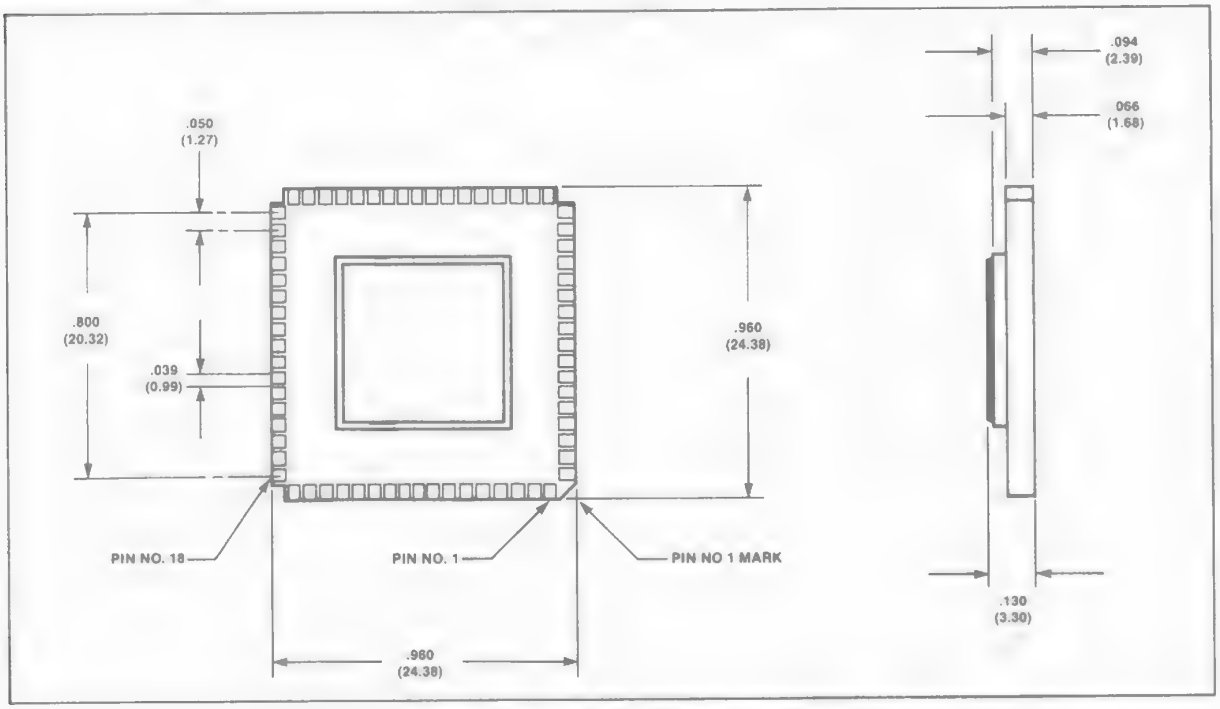


Figure 34. 80286 JEDEC Type A Package

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias . . . . . 0°C to 70°C
Storage Temperature . . . . . −65°C to +150°C
Voltage on Any Pin with
Respect to Ground . . . . . −0.3 to +7V
Power Dissipation . . . . . 3.6 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (80286: T_A = 0°C to 70°C, V_{CC} = 5V ± 10%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	+0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC}+0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL}=3.0 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH}= −400 μA
I_{CC}	Power Supply Current		600	mA	T_A=25°C
I_{LI}	Input Leakage Current		±10	μA	$0V \leq V_{IN} \leq V_{CC}$
I_{LO}	Output Leakage Current		±10	μA	$0.45V \leq V_{OUT} \leq V_{CC}$
V_{CL}	Clock Input Low voltage	−0.5	+0.6	V	
V_{CH}	Clock Input HIgh Voltage	3.8	V_{CC}+1.0	V	
C_{IN}	Capacitance of Inputs (All input except CLK)		10	pF	fc=1 MHz
C_O	Capacitance of I/O or outputs		20	pF	fc=1 MHz
C_{CLK}	Capacitance of CLK Input		12	pF	f_c=1 MHz

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ± 10%)

80286 Timing Requirements

Symbol	Parameter	Min.	Max.	Units	Test Conditions
1	System clock period	62.5	250	ns	
2	System clock low time	15	230	ns	at .6 Volts
3	System clock high time	20	235	ns	at 3.2 Volts
4	Asynchronous input setup time	20		ns	See note 1
5	Asynchronous input hold time	20		ns	See note 1
6	RESET setup time	20		ns	
7	RESET hold time	0		ns	
8	Read data in setup time	10		ns	
9	Read data in hold time	5		ns	
10	READY setup time	38.5		ns	
11	READY hold time	25		ns	
12	STATUS/$\overline{PEACK}$ valid delay	0	40	ns	C_L = 100 Pfd max
13	Address valid delay	0	60	ns	
14	Write data valid delay	0	50	ns	
15	Address/Status/Data float delay	0	60	ns	
16	HLDA valid delay	0	60	ns	

82284 Timing Requirements

Symbol	Parameter	Min.	Max.	Units	Test Conditions
17	$\overline{SRDY}$/$\overline{SRDYEN}$ setup time	15		ns	
18	$\overline{SRDY}$/$\overline{SRDYEN}$ hold time	0		ns	
19	$\overline{ARDY}$/$\overline{ARDYEN}$ setup time	−5		ns	See note 1
20	$\overline{ARDY}$/$\overline{ARDYEN}$ hold time	16		ns	See note 1.
21	PCLK delay	0	40	ns	C_L = 75 pfd I_{OL} = 5.25 ma I_{OH} = −1.05 ma

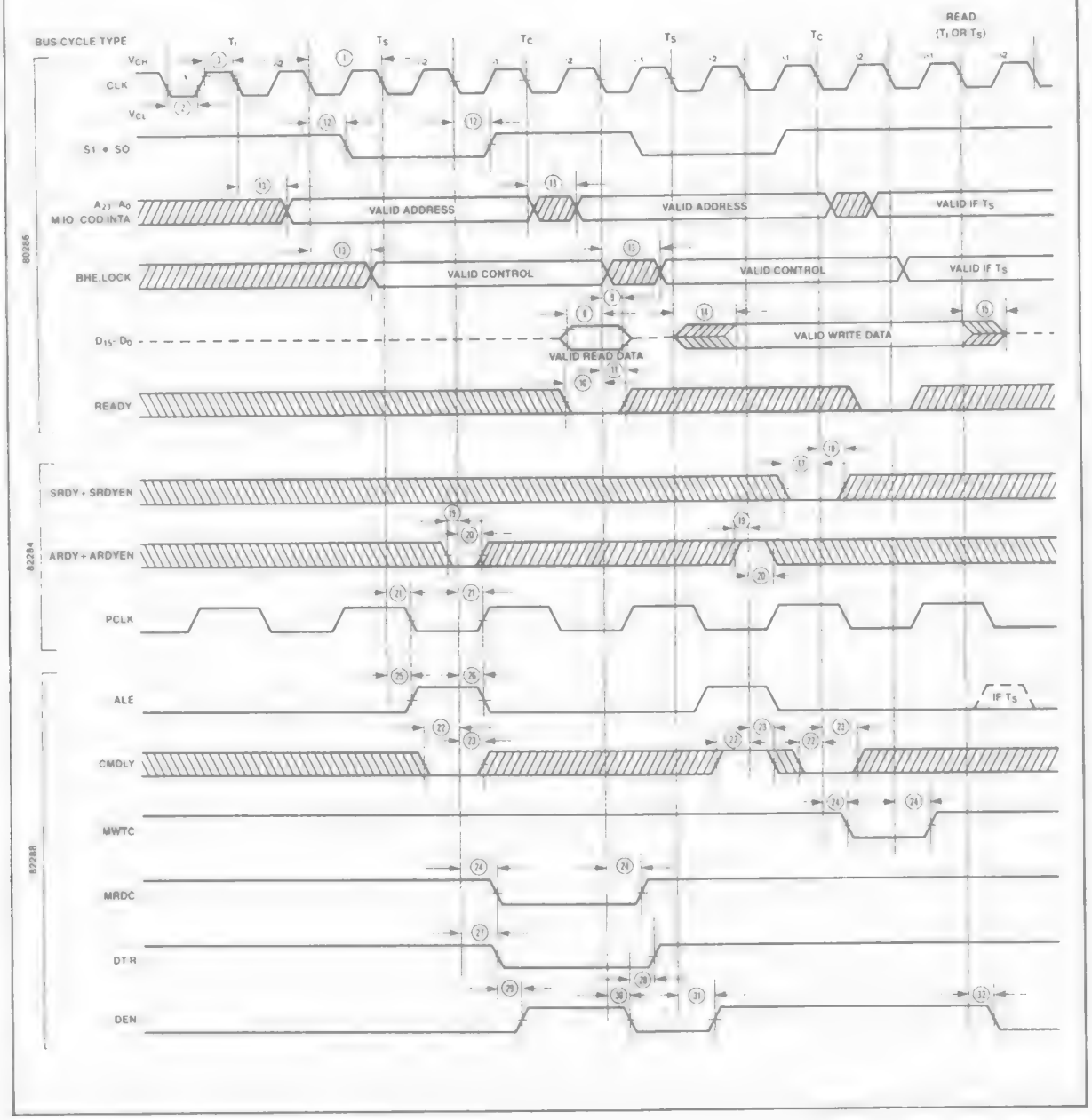
NOTE 1: These times are given for testing purposes to assure a predetermined action.

82288 Timing Requirements

Symbol	Parameter	Min.	Max.	Units	Test Conditions
22	CMDLY setup time	20		ns	
23	CMDLY hold time	0		ns	
24	Command delay	3	20	ns	C_L = 300 pfd max I_{OL} = 32 ma max I_{OH} = −5 ma max
25	ALE active delay	3	15	ns	C_L = 150 pfd max I_{OL} = 16 ma max I_{OH} = −1 ma max
26	ALE inactive delay	0	20	ns	
27	DT/$\overline{R}$ read active delay	0	20	ns	
28	DT/$\overline{R}$ read inactive delay	10	40	ns	
29	DEN read active delay	10	50	ns	
30	DEN read inactive delay	3	15	ns	
31	DEN write active delay		30	ns	
32	DEN write inactive delay	3	30	ns	

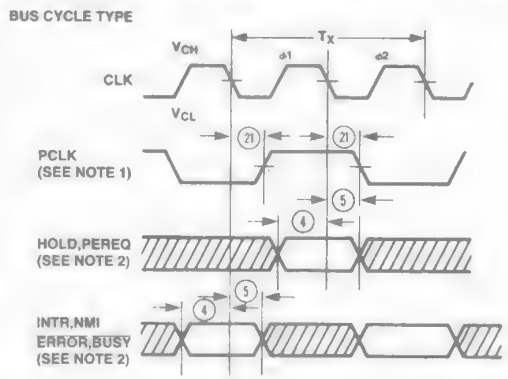
WAVEFORMS

MAJOR CYCLE TIMING



WAVEFORMS (Continued)

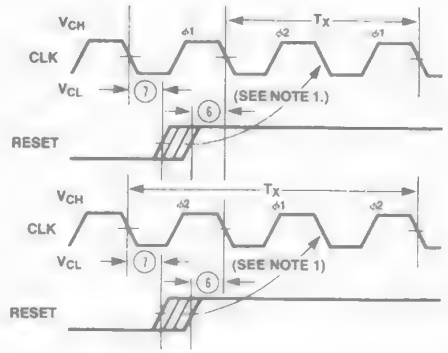
80286 ASYNCHRONOUS INPUT SIGNAL TIMING



NOTES:

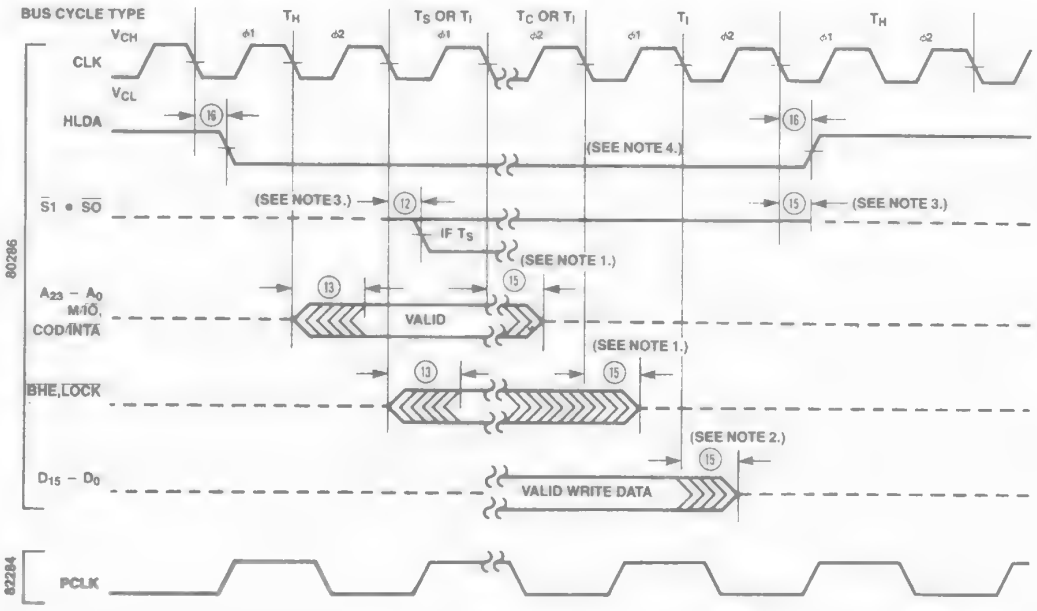
1. PCLK indicates which processor cycle phase will occur on the next CLK . PCLK may not indicate the correct phase until the first bus cycle is performed.
2. These inputs are asynchronous. The setup and hold times shown assure recognition for testing purposes.

80286 RESET INPUT TIMING AND SUBSEQUENT PROCESSOR CYCLE PHASE



NOTE 1: When RESET meets the setup time shown, the next CLK will start or repeat $\phi1$ of a processor cycle.

ENTERING AND EXITING HOLD

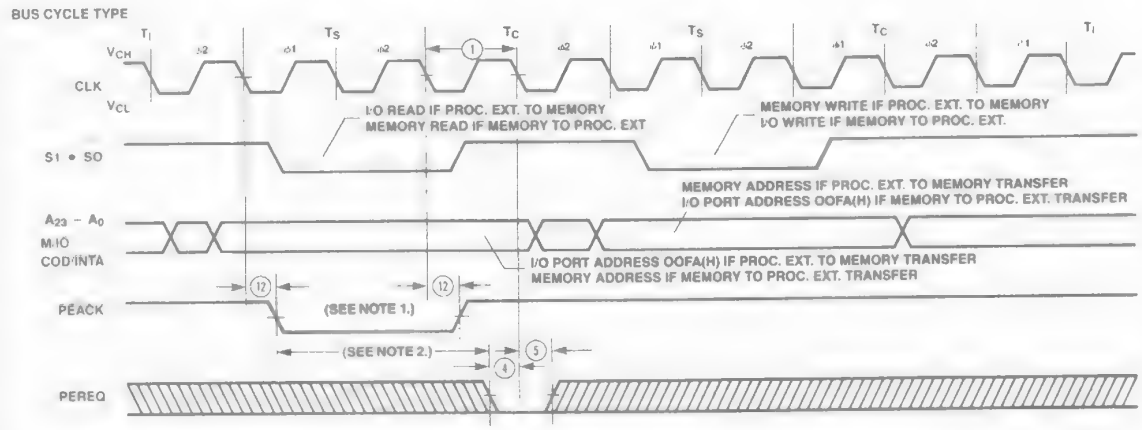


NOTES:

1. These signals may still be driven by the 80286 during the time shown. The worst case in terms of latest float time is shown.
2. The data bus will be driven as shown if the last cycle before T_I in the diagram was a write T_C.
3. The 80286 floats its status pins during T_H. External pullup resistors (in 82288) keep these signals high.
4. For HOLD request set up to HLDA, refer to Figure 29.

WAVEFORMS (Continued)

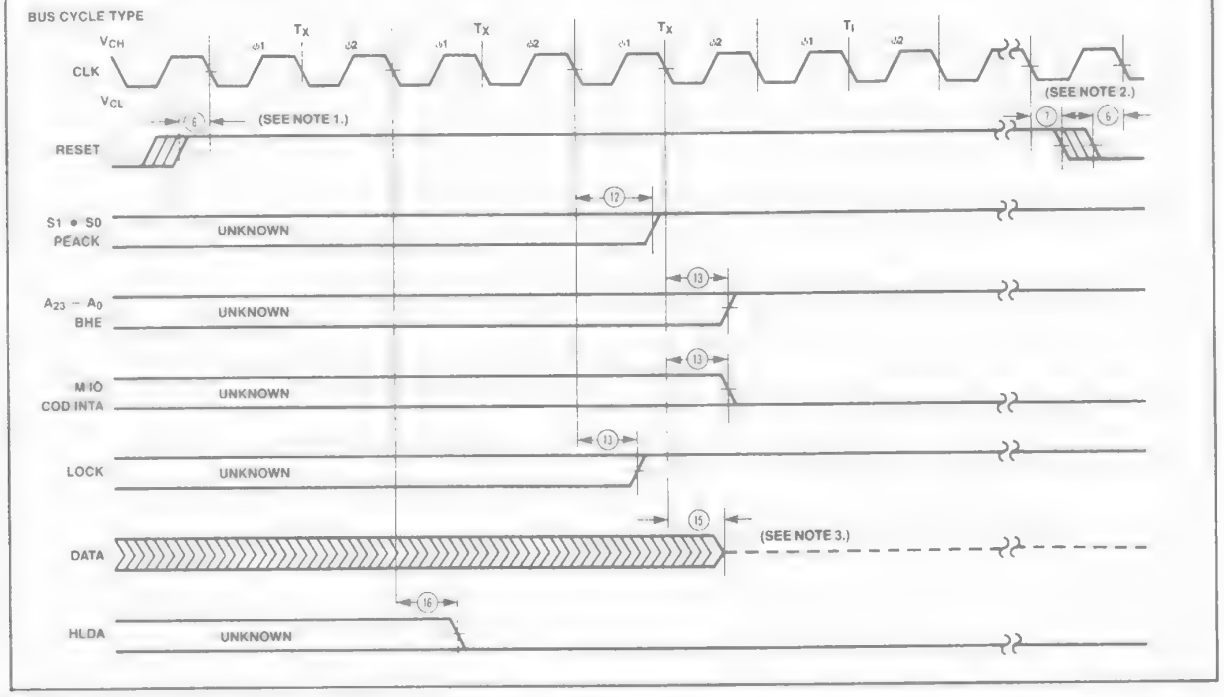
80286 PEREQ/PEACK TIMING REQUIRED PEREQ TIMING FOR ONE TRANSFER ONLY



NOTES:

1. PEACK always goes active during the first bus operation of a processor extension data operand transfer sequence. The first bus operation will be either a memory read at operand address or I/O read at port address OOFA(H).
2. To prevent a second processor extension data operand transfer, the worst case maximum time (Shown above) is: 3X(1) – (11)$_{max}$ – (4)$_{min.}$ The actual, configuration dependent, maximum time is: 3X(1) – (11)$_{max.}$ – (4)$_{min.}$ + A X 2 X (1).
   A is the number of extra T_C states added to either the first or second bus operation of the processor extension data operand transfer sequence.

INITIAL 80286 PIN STATE DURING RESET



NOTES:

1. Setup time for RESET ↑ may be violated with the consideration that $\phi 1$ of the processor clock may begin one system CLK period later.
2. Setup and hold times for RESET ↓ must be met for proper operation.
3. The data bus is only guaranteed to be in 3-state OFF at the time shown.

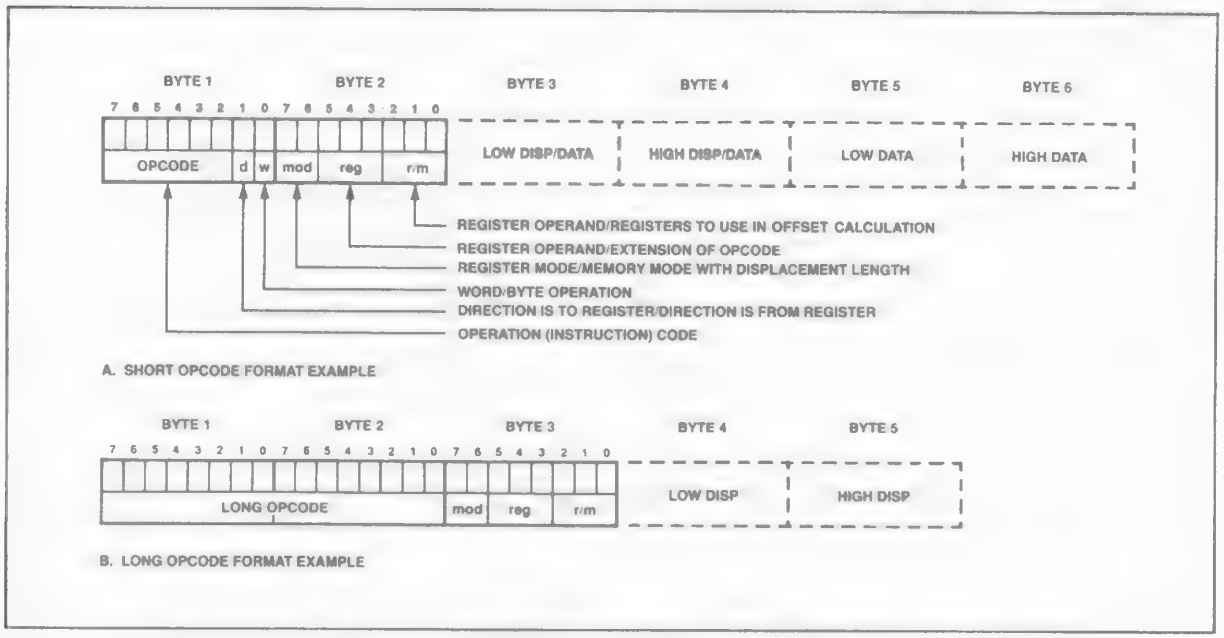


Figure 35. 80286 Instruction Format Examples

80286 INSTRUCTION SET SUMMARY

Instruction Timing Notes

The instruction clock counts listed below establish the maximum execution rate of the 80286. With no delays in bus cycles, the actual clock count of an 80286 program will average 5% more than the calculated clock count, due to instruction sequences which execute faster than they can be fetched from memory.

To calculate elapsed times for instruction sequences, multiply the sum of all instruction clock counts, as listed in the table below, by the processor clock period. An 8 MHz processor clock has a clock period of 125 nanoseconds and requires an 80286 system clock (CLK input) of 16 MHz.

Instruction Clock Count Assumptions

1. The instruction has been prefetched, decoded, and is ready for execution. Control transfer instruction clock counts include all time required to fetch, decode, and prepare the next instruction for execution.
2. Bus cycles do not require wait states.
3. There are no processor extension data transfer or local bus HOLD requests.
4. No exceptions occur during instruction execution.

Instruction Set Summary Notes

Addressing displacements selected by the MOD field are not shown. If necessary they appear after the instruction fields shown.

Above/below refers to unsigned value

Greater refers to positive signed value

Less refers to less positive (more negative) signed values

if d = 1 then to register; if d = 0 then from register

if w = 1 then word instruction; if w = 0 then byte instruction

if s = 0 then 16-bit immediate data form the operand

if s = 1 then an immediate data byte is sign-extended to form the 16-bit operand

x don't care

z used for string primitives for comparison with ZF FLAG

If two clock counts are given, the smaller refers to a register operand and the larger refers to a memory operand

* = add one clock if offset calculation requires summing 3 elements

n = number of times repeated

m = number of bytes of code in next instruction

Level (L)—Lexical nesting level of the procedure

The following comments describe possible exceptions, side effects, and allowed usage for instructions in both operating modes of the 80286.

REAL ADDRESS MODE ONLY

1. This is a protected mode instruction. Attempted execution in real address mode will result in an undefined opcode exception (6).
2. A segment overrun exception (13) will occur if a word operand reference at offset FFFF(H) is attempted.
3. This instruction may be executed in real address mode to initialize the CPU for protected mode.
4. The IOPL and NT fields will remain 0.
5. Processor extension segment overrun interrupt (9) will occur if the operand exceeds the segment limit.

EITHER MODE

6. An exception may occur, depending on the value of the operand.
7. $\overline{\text{LOCK}}$ is automatically asserted regardless of the presence or absence of the LOCK instruction prefix.

PROTECTED VIRTUAL ADDRESS MODE ONLY

8. The destination of an INT, JMP, CALL, RET or IRET instruction must be in the defined limit of a code segment or a general protection exception (13) occurs.
9. A general protection exception (13) will occur if the memory operand can not be used due to either a segment limit or access rights violation. If a stack segment limit is violated, a stack segment overrun exception (12) occurs.
10. For segment load operations, the CPL, RPL, and DPL must agree with privilege rules to avoid an exception. The segment must be present to avoid a not-present exception (11). If the SS register is the destination, and a segment not-present violation occurs, a stack exception (12) occurs.
11. All segment descriptor accesses in the GDT or LDT made by this instruction will automatically assert $\overline{\text{LOCK}}$ to maintain descriptor integrity in multiprocessor systems.
12. JMP, CALL, INT, RET, IRET instructions referring to another code segment will cause a general protection exception (13) if any privilege rule is violated.
13. A general protection exception (13) occurs if CPL $\neq$ 0.
14. A general protection exception (13) occurs if CPL > IOPL.
15. The IF field of the flag word is not updated if CPL > IOPL. The IOPL field is updated only if CPL = 0.
16. Any violation of privilege rules as applied to the selector operand do not cause a protection exception; rather, the instruction does not return a result and the zero flag is cleared.
17. If the starting address of the memory operand violates a segment limit, or an invalid access is attempted, a general protection exception (13) will occur before the ESC instruction is executed. A stack segment overrun exception (12) will occur if the stack limit is violated by the operand's starting address. If a segment limit is violated during an attempted data transfer then a processor extension segment overrun exception (9) occurs.

80286 INSTRUCTION SET SUMMARY

FUNCTION	FORMAT				CLOCK COUNT Real Address Mode	CLOCK COUNT Protected Virtual Address Mode	COMMENTS Real Address Mode	COMMENTS Protected Virtual Address Mode
DATA TRANSFER								
MOV = Move:								
Register to Register/Memory	1 0 0 0 1 0 0 w	mod reg r/m			2,3*	2,3*	2	■
Register/memory to register	1 0 0 0 1 0 1 w	mod reg r/m			2,5*	2,5*	2	9
Immediate to register/memory	1 1 0 0 0 1 1 w	mod 0 0 0 r/m	data	data if w = 1	2,3*	2,3*	2	9
Immediate to register	1 0 1 1 w reg	data	data if w = 1		2	2		
Memory to accumulator	1 0 1 0 0 0 0 w	addr-low	addr-high		5	5	2	9
Accumulator to memory	1 0 1 0 0 0 1 w	addr-low	addr-high		3	3	2	9
Register/memory to segment register	1 0 0 0 1 1 1 0	mod 0 reg r/m			2,5*	17,19*	2	9,10,11
Segment register to register/memory	1 0 0 0 1 1 0 0	mod 0 reg r/m			2,3*	2,3*	2	9
PUSH = Push:								
Memory	1 1 1 1 1 1 1 1	mod 1 1 0 r/m			5*	5*	2	9
Register	0 1 0 1 0 reg				3	3	2	■
Segment register	0 0 0 reg 1 1 0				3	3	2	9
Immediate	0 1 1 0 1 0 s 0	data	data if s = 0		3	3	2	9
PUSHA = Push All	0 1 1 0 0 0 0 0				17	17	2	9
POP = Pop:								
Memory	1 0 0 0 1 1 1 1	mod 0 0 0 r/m			5*	5*	2	9
Register	0 1 0 1 1 reg				5	5	2	■
Segment register	0 0 0 reg 1 1 1	(reg ≠ 01)			5	20	2	9,10,11
POPA = Pop All	0 1 1 0 0 0 0 1				19	19	2	9
XCHG = Exchange:								
Register/memory with register	1 0 0 0 0 1 1 w	mod reg r/m			3,5*	3,5*	2,7	7,9
Register with accumulator	1 0 0 1 0 reg				3	3		
IN = Input from:								
Fixed port	1 1 1 0 0 1 0 w	port			5	5		14
Variable port	1 1 1 0 1 1 0 w				5	5		14
OUT = Output to:								
Fixed port	1 1 1 0 0 1 1 w	port			3	3		14
Variable port	1 1 1 0 1 1 1 w				3	3		14
XLAT = Translate byte to AL	1 1 0 1 0 1 1 1				5	5		9
LEA = Load EA to register	1 0 0 0 1 1 0 1	mod reg r/m			3*	3*		
LDS = Load pointer to DS	1 1 0 0 0 1 0 1	mod reg r/m	(mod ≠ 11)		7*	21*	2	9,10,11
LES = Load pointer to ES	1 1 0 0 0 1 0 0	mod reg r/m	(mod ≠ 11)		7*	21*	2	9,10,11
LAHF = Load AH with flags	1 0 0 1 1 1 1 1				2	2		
SAHF = Store AH into flags	1 0 0 1 1 1 1 0				2	■		
PUSHF = Push flags	1 0 0 1 1 1 0 0				3	3	2	9
POPF = Pop flags	1 0 0 1 1 1 0 1				5	5	2,4	9,15

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

80286 INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT				CLOCK COUNT: Real Address Mode	CLOCK COUNT: Protected Virtual Address Mode	COMMENTS: Real Address Mode	COMMENTS: Protected Virtual Address Mode
ARITHMETIC								
ADD = Add:								
Reg/memory with register to either	0 0 0 0 0 0 d w	mod reg r/m			2,7*	2,7*	2	
Immediate to register/memory	1 0 0 0 0 0 s w	mod 0 0 0 r/m	data	data if s w = 01	3,7*	3,7*	2	9
Immediate to accumulator	0 0 0 0 0 1 0 w	data	data if w = 1		3			
ADC = Add with carry:								
Reg/memory with register to either	0 0 0 1 0 0 d w	mod reg r/m			2,7*	2,7*	2	
Immediate to register/memory	1 0 0 0 0 0 s w	mod 0 1 0 r/m	data	data if s w = 01	3,7*	3,7*	2	
Immediate to accumulator	0 0 0 1 0 1 0 w	data	data if w = 1		3	3		
INC = Increment:								
Register/memory	1 1 1 1 1 1 1 w	mod 0 0 0 r/m			2,7*	2,7*	2	9
Register	0 1 0 0 0 reg				2	2		
SUB = Subtract:								
Reg/memory and register to either	0 0 1 0 1 0 d w	mod reg r/m			2,7*	2,7*	2	
Immediate from register/memory	1 0 0 0 0 0 s w	mod 1 0 1 r/m		data if s w = 0 1	3,7*	3,7*	2	9
Immediate from accumulator	0 0 1 0 1 1 0 w	data	data if w = 1		3	3		
SBB = Subtract with borrow:								
Reg/memory and register to either	0 0 0 1 1 0 d w	mod reg r/m			2,7*	2,7*	2	9
Immediate from register/memory	1 0 0 0 0 0 s w	mod 0 1 1 r/m	data	data if s w = 0 1	3,7*	3,7*	2	
Immediate from accumulator	0 0 0 1 1 1 0 w	data	data if w = 1		3	3		
DEC = Decrement:								
Register/memory	1 1 1 1 1 1 1 w	mod 0 0 1 r/m			2,7*	2,7*	2	9
Register	0 1 0 0 1 reg				2	2		
CMP = Compare:								
Register/memory with register	0 0 1 1 1 0 1 w	mod reg r/m			2,6*	2,6*		9
Register with register/memory	0 0 1 1 1 0 0 w	mod reg r/m			2,7*	2,7*	2	9
Immediate with register/memory	1 0 0 0 0 0 s w	mod 1 1 1 r/m	data	data if s w = 0 1	3,6*	3,6*	2	9
Immediate with accumulator	0 0 1 1 1 1 0 w	data	data if w = 1		3	3		
NEG = Change sign	1 1 1 1 0 1 1 w	mod 0 1 1 r/m			2	7*	2	7
AAA = ASCII adjust for add	0 0 1 1 0 1 1 1				3	3		
DAA = Decimal adjust for add	0 0 1 0 0 1 1 1				3	3		
AAS = ASCII adjust for subtract	0 0 1 1 1 1 1 1				3	3		
DAS = Decimal adjust for subtract	0 0 1 0 1 1 1 1				3			
MUL = Multiply (unsigned):	1 1 1 1 0 1 1 w	mod 1 0 0 r/m						
Register-Byte					13	13		
Register-Word					21	21		
Memory-Byte					16*	16*	2	9
Memory-Word					24*	24*	2	
IMUL = Integer multiply (signed):	1 1 1 1 0 1 1 w	mod 1 0 1 r/m						
Register-Byte					13	13		
Register-Word					21	21		
Memory-Byte					16*	16*		
Memory-Word					24*	24*	2	9
IMUL = Integer immediate multiply (signed)	0 1 1 0 1 0 s 1	mod reg r/m	data	data if s = 0	21,24*	21,24*	2	9*
DIV = Divide (unsigned):	1 1 1 1 0 1 1 w	mod 1 1 0 r/m						
Register-Byte					14	14		
Register-Word					22	22		
Memory-Byte					17*	17*	2,6	6,9
Memory-Word					25*	25*	2,6	6,9

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

80286 INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT	CLOCK COUNT: Real Address Mode	CLOCK COUNT: Protected Virtual Address Mode	COMMENTS: Real Address Mode	COMMENTS: Protected Virtual Address Mode
ARITHMETIC (Continued):					
IDIV = Integer divide (signed):	1 1 1 1 0 1 1 w | mod 1 1 1 r/m				
Register-Byte		17	17		
Register-Word		25	25		
Memory-Byte		20*	20*	2	9
Memory-Word		28*	28*	2	9
AAM = ASCII adjust for multiply	1 1 0 1 0 1 0 0 | 0 0 0 0 1 0 1 0	16	16		
AAD = ASCII adjust for divide	1 1 0 1 0 1 0 1 | 0 0 0 0 1 0 1 0	14	14		
CBW = Convert byte to word	1 0 0 1 1 0 0 0	2	2		
CWD = Convert word to double word	1 0 0 1 1 0 0 1	2	2		
LOGIC					
Shift Rotate Instructions:					
Register/Memory by 1	1 1 0 1 0 0 0 w | mod TTT r/m	2,7*	2,7*	2	9
Register/Memory by CL	1 1 0 1 0 0 1 w | mod TTT r/m	5+n,8+n*	5+n,8+n*	2	9
Register/Memory by Count	1 1 0 0 0 0 w | mod TTT r/m | count	5+n,8+n*	5+n,8+n*	2	9
	TTT Instruction 0 0 0 ROL 0 0 1 ROR 0 1 0 RCL 0 1 1 RCR 1 0 0 SHL/SAL 1 0 1 SHR 1 1 1 SAR				
AND = And:					
Reg/memory and register to either	0 0 1 0 0 0 d w | mod reg r/m	2,7*	2,7*	2	9
Immediate to register/memory	1 0 0 0 0 0 0 w | mod 1 0 0 r/m | data | data if w = 1	3,7*	3,7*	2	9
Immediate to accumulator	0 0 1 0 0 1 0 w | data | data if w = 1	3	3		
TEST = And function to flags, no result:					
Register/memory and register	1 0 0 0 0 1 0 w | mod reg r/m	2,6*	2,6*	2	9
Immediate data and register/memory	1 1 1 1 0 1 1 w | mod 0 0 0 r/m | data | data if w = 1	3,6*	3,6*	2	9
Immediate data and accumulator	1 0 1 0 1 0 0 w | data | data if w = 1	3	3		
OR = Or:					
Reg/memory and register to either	0 0 0 0 1 0 d w | mod reg r/m	2,7*	2,7*	2	9
Immediate to register/memory	1 0 0 0 0 0 0 w | mod 0 0 1 r/m | data | data if w = 1	3,7*	3,7*	2	9
Immediate to accumulator	0 0 0 0 1 1 0 w | data | data if w = 1	3	3		
XOR = Exclusive or:					
Reg/memory and register to either	0 0 1 1 0 0 d w | mod reg r/m	2,7*	2,7*	2	9
Immediate to register/memory	1 0 0 0 0 0 0 w | mod 1 1 0 r/m | data | data if w = 1	3,7*	3,7*	2	9
Immediate to accumulator	0 0 1 1 0 1 0 w | data | data if w = 1	3	3		
NOT = Invert register/memory	1 1 1 1 0 1 1 w | mod 0 1 0 r/m	2,7*	2,7*	2	9
STRING MANIPULATION					
MOVS = Move byte/word	1 0 1 0 0 1 0 w	5	5	2	9
CMPS = Compare byte/word	1 0 1 0 0 1 1 w	8	8	2	9
SCAS = Scan byte/word	1 0 1 0 1 1 1 w	7	7	2	9
LODS = Load byte/wd to AL/AX	1 0 1 0 1 1 0 w	5	5	2	9
STOS = Stor byte/wd from AL/A	1 0 1 0 1 0 1 w	3	3	2	9
INS = Input byte/wd from DX port	0 1 1 0 1 1 0 w	5	5	2	9,14
OUTS = Output byte/wd to DX port	0 1 1 0 1 1 1 w	5	5	2	9,14

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

80286 INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT	CLOCK COUNT: Real Address Mode	CLOCK COUNT: Protected Virtual Address Mode	COMMENTS: Real Address Mode	COMMENTS: Protected Virtual Address Mode
STRING MANIPULATION (Continued):					
Repeated by count in CX					
MOVS = Move string	1 1 1 1 0 0 1 0 | 1 0 1 0 0 1 0 w	5+4n	5+4n	2	[illegible]
CMPS = Compare string	1 1 1 1 0 0 1 z | 1 0 1 0 0 1 1 w	5+9n	5+9n	2	9
SCAS = Scan string	1 1 1 1 0 0 1 z | 1 0 1 0 1 1 1 w	5+8n	5+8n	2	[illegible]
LODS = Load string	1 1 1 1 0 0 1 0 | 1 0 1 0 1 1 0 w	5+4n	5+4n	2	9
STOS = Store string	1 1 1 1 0 0 1 0 | 1 0 1 0 1 0 1 w	4+3n	4+3n	[illegible]	[illegible]
INS = Input string	1 1 1 1 0 0 1 0 | 0 1 1 0 1 1 0 w	5+4n	5+4n	2	9,14
OUTS = Output string	1 1 1 1 0 0 1 0 | 0 1 1 0 1 1 1 w	5+4n	5+4n	2	9,14
CONTROL TRANSFER					
CALL = Call:					
Direct within segment	1 1 1 0 1 0 0 0 | disp-low | disp-high	7+m	7+m	2	[illegible]
Register/memory indirect within segment	1 1 1 1 1 1 1 1 | mod 0 1 0 r/m	7+m,11+m*	7+m,11+m*	2	8,9
Direct intersegment	1 0 0 1 1 0 1 0 | segment offset | segment selector	13+m	26+m	2	8,11,12
Protected Mode Only (Direct intersegment):					
Via call gate to same privilege level			41+m		8,11,12
Via call gate to different privilege level, no parameters			82+m		8,11,12
Via call gate to different privilege level, x parameters			86+4x+m		8,11,12
Via TSS			177+m		8,11,12
Via task gate			182+m		8,11,12
Indirect intersegment	1 1 1 1 1 1 1 1 | mod 0 1 1 r/m (mod ≠ 11)	16+m	29+m*	2	8,9,11,12
Protected Mode Only (Indirect intersegment):					
Via call gate to same privilege level			44+m*		8,9,11,12
Via call gate to different privilege level, no parameters			83+m*		8,9,11,12
Via call gate to different privilege level, x parameters			90+4x+m*		8,9,11,12
Via TSS			180+m*		8,9,11,12
Via task gate			185+m*		8,9,11,12
JMP = Unconditional jump:					
Short/long	1 1 1 0 1 0 1 1 | disp-low	7+m	7+m		8
Direct within segment	1 1 1 0 1 0 0 1 | disp-low | disp-high	7+m	7+m		8
Register/memory indirect within segment	1 1 1 1 1 1 1 1 | mod 1 0 0 r/m	7+m,11+m*	7+m,11+m*	2	8,9
Direct intersegment	1 1 1 0 1 0 1 0 | segment offset | segment selector	11+m	23+m		8,11,12
Protected Mode Only (Direct intersegment):					
Via call gate to same privilege level			38+m		8,11,12
Via TSS			175+m		8,11,12
Via task gate			180+m		8,11,12
Indirect intersegment	1 1 1 1 1 1 1 1 | mod 1 0 1 r/m (mod ≠ 11)	15+m*	26+m*	2	8,9,11,12
Protected Mode Only (Indirect intersegment):					
Via call gate to same privilege level			41+m*		8,9,11,12
Via TSS			178+m*		8,9,11,12
Via task gate			183+m*		8,9,11,12
RET = Return from CALL:					
Within segment	1 1 0 0 0 0 1 1	11+m	11+m	2	8,9
Within seg adding immed to SP	1 1 0 0 0 0 1 0 | data-low | data-high	11+m	11+m	2	8,9
Intersegment	1 1 0 0 1 0 1 1	15+m	25+m	2	8,9,11,12
Intersegment adding immediate to SP	1 1 0 0 1 0 1 0 | data-low | data-high	15+m		2	8,9,11,12
Protected Mode Only (RET):					
To different privilege level			55+m		

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

80286 INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT	CLOCK COUNT: Real Address Mode	CLOCK COUNT: Protected Virtual Address Mode	COMMENTS: Real Address Mode	COMMENTS: Protected Virtual Address Mode
CONTROL TRANSFER (Continued):					
JE/JZ = Jump on equal/zero	0 1 1 1 0 1 0 0 disp	7+m or 3	7+m or 3		8
JL/JNGE = Jump on less/not greater or equal	0 1 1 1 1 1 0 0 disp	7+m or 3	7+m or 3		8
JLE/JNG = Jump on less or equal/not greater	0 1 1 1 1 1 1 0 disp	7+m or 3	7+m or 3		8
JB/JNAE = Jump on below/not above or equal	0 1 1 1 0 0 1 0 disp	7+m or 3	7+m or 3		8
JBE/JNA = Jump on below or equal/not above	0 1 1 1 0 1 1 0 disp	7+m or 3	7+m or 3		8
JP/JPE = Jump on parity/parity even	0 1 1 1 1 0 1 0 disp	7+m or 3	7+m or 3		8
JO = Jump on overflow	0 1 1 1 0 0 0 0 disp	7+m or 3	7+m or 3		8
JS = Jump on sign	0 1 1 1 1 0 0 0 disp	7+m or 3	7+m or 3		8
JNE/JNZ = Jump on not equal/not zero	0 1 1 1 0 1 0 1 disp	7+m or 3	7+m or 3		8
JNL/JGE = Jump on not less/greater or equal	0 1 1 1 1 1 0 1 disp	7+m or 3	7+m or 3		8
JNLE/JG = Jump on not less or equal/greater	0 1 1 1 1 1 1 1 disp	7+m or 3	7+m or 3		8
JNB/JAE = Jump on not below/above or equal	0 1 1 1 0 0 1 1 disp	7+m or 3	7+m or 3		8
JNBE/JA = Jump on not below or equal/above	0 1 1 1 0 1 1 1 disp	7+m or 3	7+m or 3		8
JNP/JPO = Jump on not par/par odd	0 1 1 1 1 0 1 1 disp	7+m or 3	7+m or 3		8
JNO = Jump on not overflow	0 1 1 1 0 0 0 1 disp	7+m or 3	7+m or 3		8
JNS = Jump on not sign	0 1 1 1 1 0 0 1 disp	7+m or 3	7+m or 3		8
LOOP = Loop CX times	1 1 1 0 0 0 1 0 disp	8+m or 4	8+m or 4		8
LOOPZ/LOOPE = Loop while zero/equal	1 1 1 0 0 0 0 1 disp	8+m or 4	8+m or 4		8
LOOPNZ/LOOPNE = Loop while not zero/equal	1 1 1 0 0 0 0 0 disp	8+m or 4	8+m or 4		8
JCXZ = Jump on CX zero	1 1 1 0 0 0 1 1 disp	8+m or 4	8+m or 4		8
ENTER = Enter Procedure	1 1 0 0 1 0 0 0 data-low data-high L 0	11	11	2	9
L = 1		15	15	2	9
L > 1		15+4(L-1)	15+4(L-1)	2	9
LEAVE = Leave Procedure	1 1 0 0 1 0 0 1	5	5	2	9
INT = Interrupt:					
Type specified	1 1 0 0 1 1 0 1 type	23+m		2	
Type 3	1 1 0 0 1 1 0 0	23+m		2	
INTO = Interrupt on overflow	1 1 0 0 1 1 1 0	24+m or 3 (3 if no interrupt)	24+m or 3 (3 if no interrupt)	2	
Protected Mode Only:					
Via interrupt or trap gate to same privilege level			40+m		8,11,12
Via interrupt or trap gate to fit different privilege level			78+m		8,11,12
Via Task Gate			167+m		8,11,12
IRET = Interrupt return	1 1 0 0 1 1 1 1	17+m	31+m	2,4	8,9,11,12,15
Protected Mode Only:					
To different privilege level			55+m		8,9,11,12,15
To different task (NT = 1)			169+m		8,9,11,12
BOUND = Detect value out of range	0 1 1 0 0 0 1 0 mod reg r/m	13*	13* (* if no exception 5)	2,6	6,8,9,11,12

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

80286 INSTRUCTION SET SUMMARY (Continued)

FUNCTION	FORMAT	CLOCK COUNT Real Address Mode	CLOCK COUNT Protected Virtual Address Mode	COMMENTS Real Address Mode	COMMENTS Protected Virtual Address Mode
PROCESSOR CONTROL					
CLC = Clear carry	1 1 1 1 1 0 0 0	2	2		
CMC = Complement carry	1 1 1 1 0 1 0 1	2	2		
STC = Set carry	1 1 1 1 1 0 0 1	2	2		
CLD = Clear direction	1 1 1 1 1 1 0 0	2	2		
STD = Set direction	1 1 1 1 1 1 0 1	2	2		
CLI = Clear interrupt	1 1 1 1 1 0 1 0	3	3		14
STI = Set interrupt	1 1 1 1 1 0 1 1	2	2		14
HLT = Halt	1 1 1 1 0 1 0 0	2	2		13
WAIT = Wait	1 0 0 1 1 0 1 1	3	3		
LOCK = Bus lock prefix	1 1 1 1 0 0 0 0	0	0		14
CTS = Clear taskswitched flag	0 0 0 0 1 1 1 1 | 0 0 0 0 0 1 1 0	2	2	3	13
ESC = Processor Extension Escape	1 1 0 1 1 T T T | mod L L L r/m (TTT LLL are opcode to processor extension)	9-20*	9-20*	5	17
PROTECTION CONTROL					
LGDT	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 0 1 | mod 0 1 0 r/m	11	11*	2,3	9,13
SGDT	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 0 1 | mod 0 0 1 r/m	11	11*	2,3	9
LIDT	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 0 1 | mod 0 1 1 r/m	11	11*	2,3	9,13
SIDT	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 0 1 | mod 0 0 1 r/m	11	11*	2,3	9
LLDT	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 0 1 | mod 0 1 0 r/m		19/20*	1	9,13
SLDT	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 0 1 | mod 0 0 0 r/m		2/3*	1	9
LTR	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 0 1 | mod 0 1 1 r/m		19/20*	1	9,13
STR	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 0 1 | mod 0 0 1 r/m		2/3*		9,13
LMSW	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 0 1 | mod 1 1 0 r/m	3/6	3/6*	2,3	9,13
SMSW = Store machine status word	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 0 1 | mod 1 1 1 r/m	2/3	2/3*	2,3	9
LAR	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 1 0 | mod r/m		14/16*	1	9,16
LSL	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 1 1 | mod r/m		14/16*	1	9,16
ARPL	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 1 1 | mod r/m		10/20*	1	9
VERR	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 1 1 | mod 1 0 0 r/m		11/13*	1	9,16
VERR	0 1 1 1 1 1 1 1 | 0 0 0 0 0 0 1 1 | mod 1 0 1 r/m		14/16*	1	9,16

Shaded areas indicate instructions not available in iAPX 86, 88 microsystems.

Footnotes

The effective Address (EA) of the memory operand is computed according to the mod and r/m fields:

if mod = 11 then r/m is treated as a REG field
if mod = 00 then DISP = 0*, disp-low and disp-high are absent
if mod = 01 then DISP = disp-low sign-extended to 16-bits, disp-high is absent
if mod = 10 then DISP = disp-high: disp-low

if r/m = 000 then EA = (BX) + (SI) + DISP
if r/m = 001 then EA = (BX) + (DI) + DISP
if r/m = 010 then EA = (BP) + (SI) + DISP
if r/m = 011 then EA = (BP) + (DI) + DISP
if r/m = 100 then EA = (SI) + DISP
if r/m = 101 then EA = (DI) + DISP
if r/m = 110 then EA = (BP) + DISP*
if r/m = 111 then EA = (BX) + DISP

DISP follows 2nd byte of instruction (before data if required)

*except if mod = 00 and r/m = 110 then EA = disp-high: disp-low.

SEGMENT OVERRIDE PREFIX

0	0	1	reg	1	1	0

reg is assigned according to the following:

reg	Segment Register
00	ES
01	CS
10	SS
11	DS

REG is assigned according to the following table:

16-Bit (w = 1)	8-Bit (w = 0)
000 AX	000 AL
001 CX	001 CL
010 DX	010 DL
011 BX	011 BL
100 SP	100 AH
101 BP	101 CH
110 SI	110 DH
111 DI	111 BH

The physical addresses of all operands addressed by the BP register are computed using the SS segment register. The physical addresses of the destination operands of the string primitive operations (those addressed by the DI register) are computed using the ES segment, which may not be overridden.

82284
CLOCK GENERATOR AND READY INTERFACE FOR iAPX 286 PROCESSORS

- **Generates System Clock for iAPX 286 Processors**
- **Uses Crystal or TTL Signal for Frequency Source**
- **Provides Local READY and Multibus* READY Synchronization**
- **18-pin Package**
- **Single +5V Power Supply**
- **Generates System Reset Output from Schmitt Trigger Input**
- **Available in EXPRESS**
  - **Standard Temperature Range**
  - **Extended Temperature Range**

The 82284 is a clock generator/driver which provides clock signals for iAPX 286 processors and support components. It also contains logic to supply $\overline{\text{READY}}$ to the CPU from either asynchronous or synchronous sources and synchronous RESET from an asynchronous input with hysteresis.

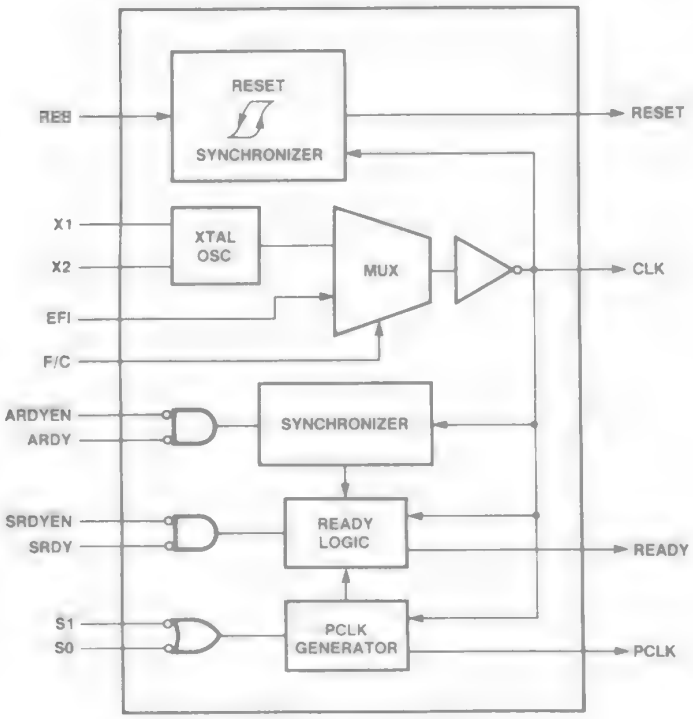


Figure 1. 82284 Block Diagram

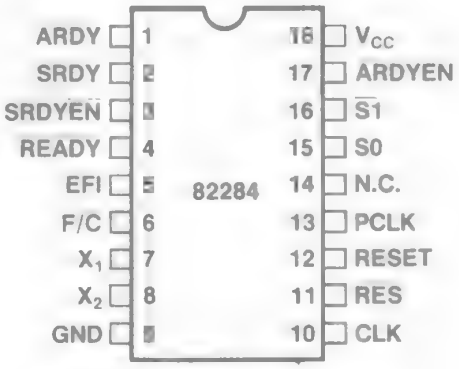


Figure 2.
82284 Pin Configuration

* Multibus is a patented bus of Intel

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MAY 1982
ORDER NUMBER: 210453-001

Table 1. Pin Description

The following pin function descriptions are for the 82284 clock generator.

Symbol	Type	Name and Function
CLK	O	**System Clock** is the signal used by the processor and support devices which must be synchronous with the processor. The frequency of the CLK output has twice the desired internal processor clock frequency. CLK can drive both TTL and MOS level inputs.
F/$\overline{C}$	I	**Frequency/Crystal Select** is a strapping option to select the source for the CLK output. When F/$\overline{C}$ is strapped LOW, the internal crystal oscillator drives CLK. When F/$\overline{C}$ is strapped HIGH, the EFI input drives the CLK output.
X1, X2	I	**Crystal In** are the pins to which a parallel resonant fundamental mode crystal is attached for the internal oscillator. When F/$\overline{C}$ is LOW, the internal oscillator will drive the CLK output at the crystal frequency. The crystal frequency must be twice the desired internal processor clock frequency.
EFI	I	**External Frequency In** drives CLK when the F/$\overline{C}$ input is strapped HIGH. The EFI input frequency must be twice the desired internal processor clock frequency.
PCLK	O	**Peripheral Clock** is an output which provides a 50% duty cycle clock with 1/2 the frequency of CLK. PLCK will be in phase with the internal processor clock following the first bus cycle after the processor has been reset.
$\overline{ARDYEN}$	I	**Asynchronous Ready Enable** is an active LOW input which qualifies the $\overline{ARDY}$ input. $\overline{ARDYEN}$ selects $\overline{ARDY}$ as the source of ready for the current bus cycle. Inputs to $\overline{ARDYEN}$ may be applied asynchronously to CLK. Setup and hold times are given to assure a guaranteed response to synchronous inputs.
$\overline{ARDY}$	I	**Asynchronous Ready** is an active LOW input used to terminate the current bus cycle. The $\overline{ARDY}$ input is qualified by $\overline{ARDYEN}$. Inputs to $\overline{ARDY}$ may be applied asynchronously to CLK. Setup and hold times are given to assure a guaranteed response to synchronous inputs.
$\overline{SRDYEN}$	I	**Synchronous Ready Enable** is an active LOW input which qualifies $\overline{SRDY}$. $\overline{SRDYEN}$ selects $\overline{SRDY}$ as the source for $\overline{READY}$ to the CPU for the current bus cycle. Setup and hold times must be satisfied for proper operation.
$\overline{SRDY}$	I	**Synchronous Ready** is an active LOW input used to terminate the current bus cycle. The $\overline{SRDY}$ input is qualified by the $\overline{SRDYEN}$ input. Setup and hold times must be satisfied for proper operation.
$\overline{READY}$	O	**Ready** is an active LOW output which signals the current bus cycle is to be completed. The $\overline{SRDY}$, $\overline{SRDYEN}$, $\overline{ARDY}$, $\overline{ARDYEN}$, $\overline{S1}$, $\overline{S0}$ and $\overline{RES}$ inputs control $\overline{READY}$ as explained later in the $\overline{READY}$ generator section. $\overline{READY}$ is an open collector output requiring an external 300 ohm pullup resistor.
$\overline{S0}$, $\overline{S1}$	I	**Status** inputs prepare the 82284 for a subsequent bus cycle. $\overline{S0}$ and $\overline{S1}$ synchronize PCLK to the internal processor clock and control $\overline{READY}$. These inputs have pullup resistors to keep them HIGH if nothing is driving them. Setup and hold times must be satisfied for proper operation.
RESET	O	**Reset** is an active HIGH output which is derived from the $\overline{RES}$ input. RESET is used to force the system into an initial state. When RESET is active, $\overline{READY}$ will be active (LOW).
$\overline{RES}$	I	**Reset In** is an active LOW input which generates the system reset signal RESET. Signals to $\overline{RES}$ may be applied asynchronously to CLK. A Schmitt trigger input is provided on $\overline{RES}$, so that an RC circuit can be used to provide a time delay. Setup and hold times are given to assure a guaranteed response to synchronous inputs.
V_{CC}		**System Power**: +5V power supply
GND		**System Ground**: 0 volts

FUNCTIONAL DESCRIPTION

Introduction

The 82284 generates the clock, ready, and reset signals required for iAPX 286 processors and support components. The 82284 is packaged in an 18-pin DIP and contains a crystal controlled oscillator, MOS clock generator, peripheral clock generator, Multibus ready synchronization logic and system reset generation logic.

Clock Generator

The CLK output provides the basic timing control for an iAPX 286 system. CLK has output characteristics sufficient to drive MOS devices. CLK is generated by either an internal crystal oscillator or an external source as selected by the F/$\overline{C}$ strapping option. When

F/$\overline{C}$ is LOW, the crystal oscillator drives the CLK output. When F/$\overline{C}$ is HIGH, the EFI input drives the CLK output.

The 82284 provides a second clock output (PCLK) for peripheral devices. PCLK is CLK divided by two. PCLK has a duty cycle of 50% and TTL output drive characteristics. PCLK is normally synchronized to the internal processor clock.

After reset, the PCLK signal may be out of phase with the internal processor clock. The $\overline{S1}$ and $\overline{S0}$ signals of the first bus cycle are used to synchronize PCLK to the internal processor clock. The phase of the PCLK output changes by extending its HIGH time beyond one system clock (see waveforms). PCLK is forced HIGH whenever either $\overline{S0}$ or $\overline{S1}$ were active (LOW) for the two previous CLK cycles. PCLK continues to oscillate when both $\overline{S0}$ and $\overline{S1}$ are HIGH.

Since the phase of the internal processor clock will not change except during reset, the phase of PCLK will not change except during the first bus cycle after reset.

Oscillator

The oscillator circuit of the 82284 is a linear Pierce oscillator which requires an external parallel resonant, fundamental mode, crystal. The output of the oscillator is internally buffered. The crystal frequency chosen should be twice the required internal processor clock frequency. The crystal should have a typical load capacitance of 32 pF.

X1 and X2 are the oscillator crystal connections. For stable operation of the oscillator, two loading capacitors are recommended, as shown in Figure 3. The sum of the board capacitance and loading capacitance should equal the values shown. It is advisable to limit stray board capacitances (not including the effect of the loading capacitors or crystal capacitance) to less than 10 pF between the X1 and X2 pins.

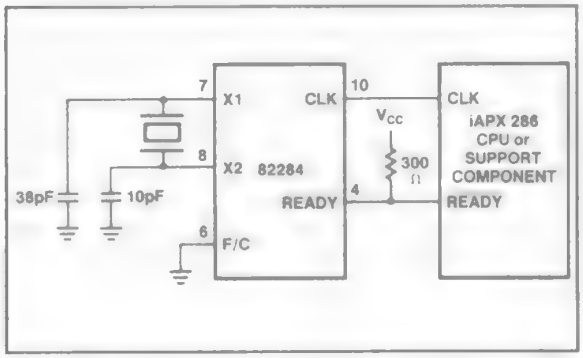


Figure 3. Recommended Crystal and Ready Connections

Reset Operation

The reset logic provides the RESET output to force the system into a known, initial state. When the $\overline{RES}$ input is active (LOW), the RESET output becomes active (HIGH). $\overline{RES}$ is synchronized internally at the falling edge of CLK before generating the RESET output (see waveforms). Synchronization of the $\overline{RES}$ input introduces a one or two CLK delay before affecting the RESET output.

At power up, a system does not have a stable V_{CC} and CLK. To prevent spurious activity, $\overline{RES}$ should be asserted until V_{CC} and CLK stabilize at their operating values. iAPX 286 processors and support components also require their RESET inputs be HIGH a minimum number of CLK cycles. An RC network, as shown in Figure 4, will keep $\overline{RES}$ LOW long enough to satisfy both needs.

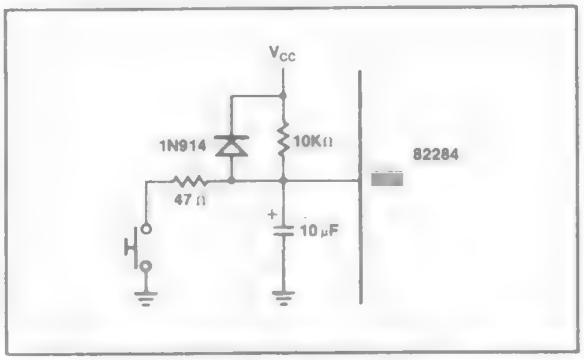


Figure 4. Typical RC RESET Timing Circuit

A Schmitt trigger input with hysteresis on $\overline{RES}$ assures a single transition of RESET with an RC circuit on $\overline{RES}$. The hysteresis separates the input voltage level at which the circuit output switches between HIGH to LOW from the input voltage level at which the circuit output switches between LOW to HIGH. The $\overline{RES}$ HIGH to LOW input transition voltage is lower than the $\overline{RES}$ LOW to HIGH input transition voltage. As long as the slope of the $\overline{RES}$ input voltage remains in the same direction (increasing or decreasing) around the $\overline{RES}$ input transition voltage, the RESET output will make a single transition.

Ready Operation

The 82284 accepts two ready sources for the system ready signal which terminates the current bus cycle. Either a synchronous ($\overline{SRDY}$) or asynchronous ready ($\overline{ARDY}$) source may be used. Each ready input has an enable ($\overline{SRDYEN}$ and $\overline{ARDYEN}$) for selecting the type of ready source required to terminate the current bus cycle. An address decoder would normally select one of the enable inputs.

$\overline{READY}$ is enabled (LOW), if either $\overline{SRDY}$ + $\overline{SRDYEN}$ = 0 or $\overline{ARDY}$ + $\overline{ARDYEN}$ = 0 when sampled by the 82284 $\overline{READY}$ generation logic. $\overline{READY}$ will remain active for at least two CLK cycles.

The $\overline{READY}$ output has an open-collector driver allowing other ready circuits to be wire or'ed with it. The $\overline{READY}$ signal of an iAPX 286 system requires an external 300 ohm pull-up resistor. To force the $\overline{READY}$ signal inactive (HIGH) at the start of a bus cycle, the $\overline{READY}$ output floats when either $\overline{S1}$ or $\overline{S0}$ are sampled LOW at the falling edge of CLK. Two system clock periods are allowed for the pull-up resistor to pull the $\overline{READY}$ signal to V_{IH}. When RESET is active, $\overline{READY}$ is forced active one CLK later (see waveforms).

Figure 5 illustrates the operation of $\overline{SRDY}$ and $\overline{SRDYEN}$. These inputs are sampled on the falling edge of CLK when $\overline{S1}$ and $\overline{S0}$ are inactive and PCLK is HIGH. $\overline{READY}$ is forced active when both $\overline{SRDY}$ and $\overline{SRDYEN}$ are sampled as LOW.

Figure 6 shows the operation of $\overline{ARDY}$ and $\overline{ARDYEN}$. These inputs are sampled by an internal synchronizer at each falling edge of CLK. The output of the synchronizer is then sampled when PCLK is HIGH. If the synchronizer resolved both the $\overline{ARDY}$ and $\overline{ARDYEN}$ inputs to have been LOW, $\overline{READY}$ becomes LOW. When both $\overline{ARDY}$ and $\overline{ARDYEN}$ have been resolved as active, the $\overline{SRDY}$ and $\overline{SRDYEN}$ inputs are ignored.

$\overline{READY}$ remains active until either $\overline{S1}$ or $\overline{S0}$ are sampled LOW, or the ready inputs are sampled as inactive.

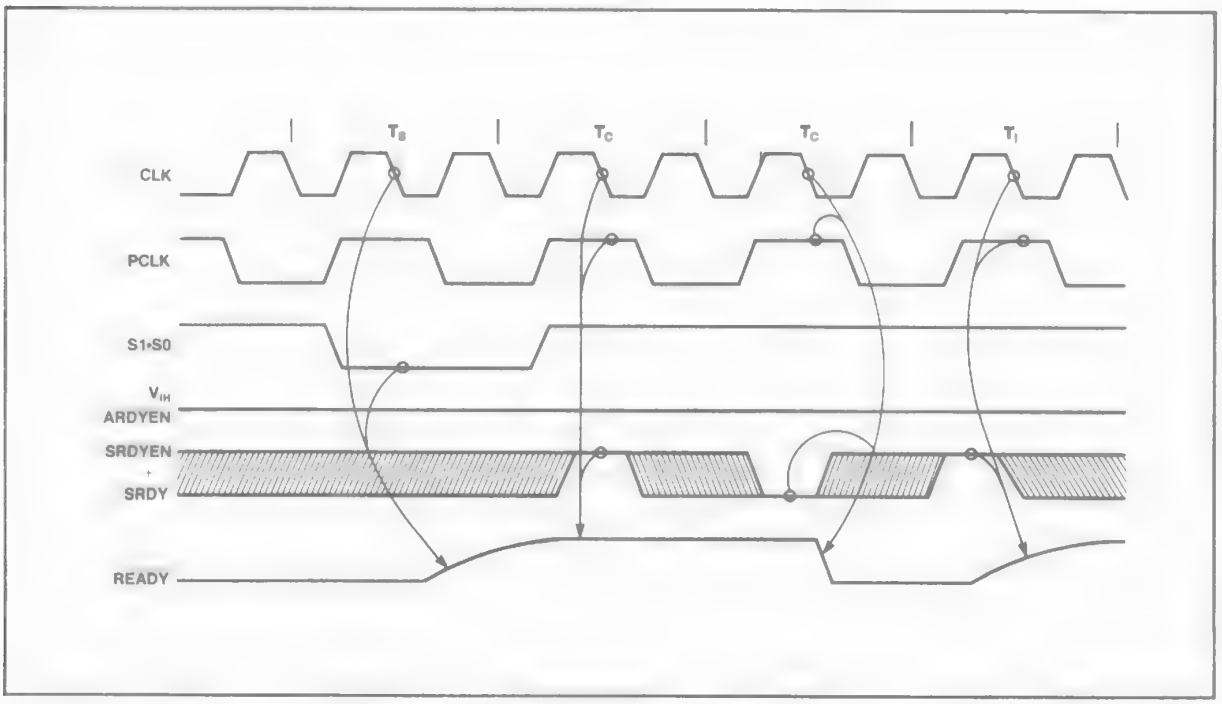


Figure 5. Synchronous Ready Operation

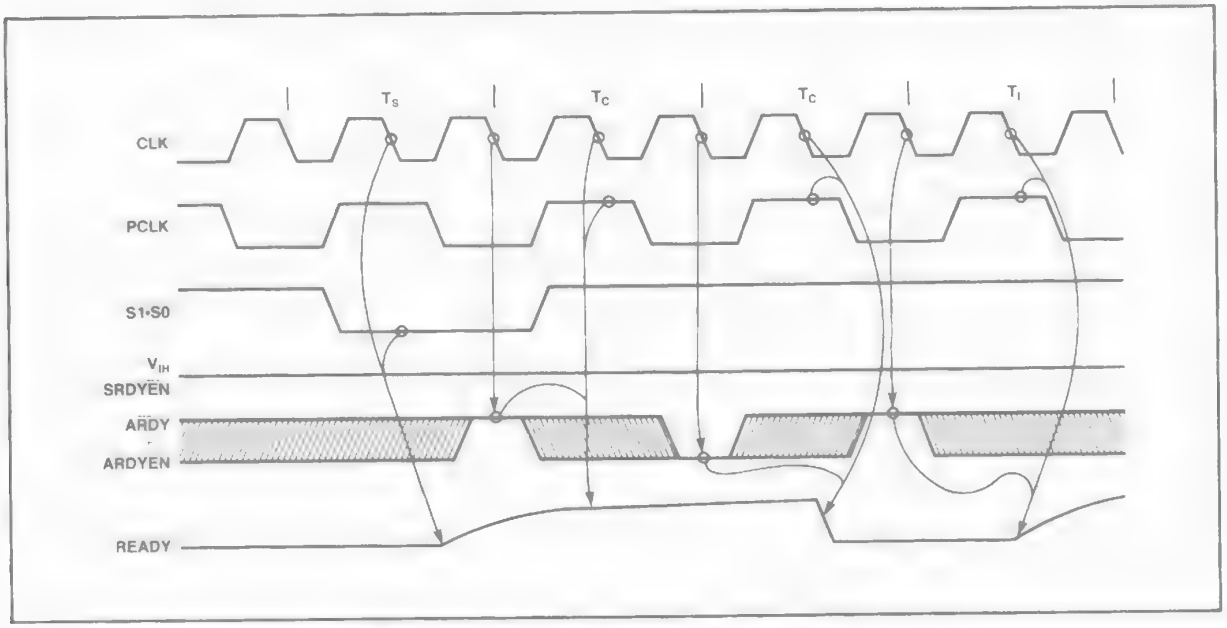


Figure 6. Asynchronous Ready Operation

ABSOLUTE MAXIMUM RATINGS*

Temperature Under Bias . . . . . 0°C to 70°C

Storage Temperature . . . . . -65°C to +150°C

All Output and Supply Voltages . . . . . -0.5V to +7V

All Input Voltages . . . . . -1.0V to +5.5V

Power Dissipation . . . . . 1 Watt

**Notice: Stresses above those listed under "Absolute Maxmum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ± 10%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
I_F	Forward Input Current		−0.5	mA	V_F = 0.45V
I_R	Reverse Input Current		50	uA	V_R = 5.25V
V_C	Input Forward Clamp Voltage		-1.0	V	I_C = -5 mA
I_{CC}	Power Supply Current		145	mA	
V_{IL}	Input LOW Voltage		0.8	V	
V_{IH}	Input HIGH Voltage	2.0		V	
V_{OL},V_{CL}	Output LOW Voltage		0.45	V	I_{OL} = 5 mA
V_{CH}	CLK Output HIGH Voltage	4.0		V	I_{OH} = -1 mA
V_{OH}	Output HIGH Voltage	2.4		V	I_{OH} = -1 mA
V_{IH_R}	$\overline{RES}$ Input HIGH Voltage	2.6		V	
V_{IH_R}-V_{IL_R}	$\overline{RES}$ Input Hysteresis	0.25		V	
C_I	Input Capacitance		10	pF	

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ± 10%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
t_1	EFI to CLK Delay		40	ns	at 1.5V C_L = 150 pF I_{OL} = 5 ma
t_2	EFI LOW Time	32		ns	
t_3	EFI HIGH Time	28		ns	
t_4	CLK Period	55	500	ns	
t_5	CLK LOW Time	15		ns	at 0.6V See Note 1. at 3.8V
t_6	CLK HIGH Time	20		ns	
t_7	CLK Rise Time		10	ns	From 1.0V to 3.5V See Note 2. From 3.5V to 1.0V
t_8	CLK Fall Time		10	ns	
t_9	Status Setup Time	22.5		ns	at 0.8V and 2.0V on input and 0.8V on CLK
t_{10}	Status Hold Time	0		ns	
t_{11}	$\overline{SRDY}$+$\overline{SRDYEN}$ Setup Time	15		ns	
t_{12}	$\overline{SRDY}$+$\overline{SRDYEN}$ Hold Time	0		ns	
t_{13}	$\overline{ARDY}$+$\overline{ARDYEN}$ Setup Time	0		ns	
t_{14}	$\overline{ARDY}$+$\overline{ARDYEN}$ Hold Time	16		ns	
t_{15}	$\overline{RES}$ Setup Time	16		ns	
t_{16}	$\overline{RES}$ Hold Time	0		ns	
t_{17}	$\overline{READY}$ Inactive Delay	[illegible]		ns	at 0.8V C_L = 150 pF I_{OL} = 20 mA
t_{18}	$\overline{READY}$ Active Delay	0	24	ns	
t_{19}	PCLK Delay	0	40	ns	at 0.8V on CLK to See Note 3. 0.8V or 2.0V on output
t_{20}	RESET Delay	0	40	ns	
t_{21}	PCLK Low Time	t_4-12.5		ns	at 0.6V See Note 3. at 3.8V
t_{22}	PCLK High Time	t_4-12.5		ns	

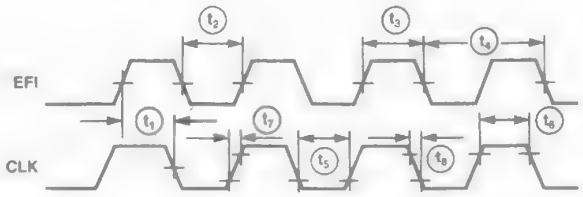
Note 1. C_L = 150 pF, I_{OL} = 5 ma. With either the internal oscillator with the recommended crystal and load or the EFI input.

Note 2. C_L = 150 pF
I_{OL} = 5 mA

Note 3. I_{OL} = 5 mA
C_L = 75 pF

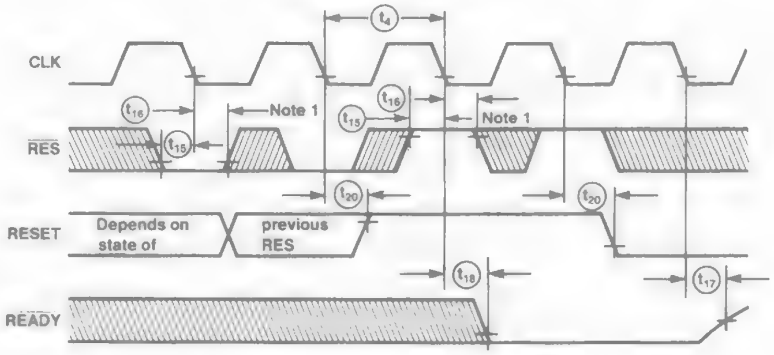
Waveforms

CLK as a Function of EFI



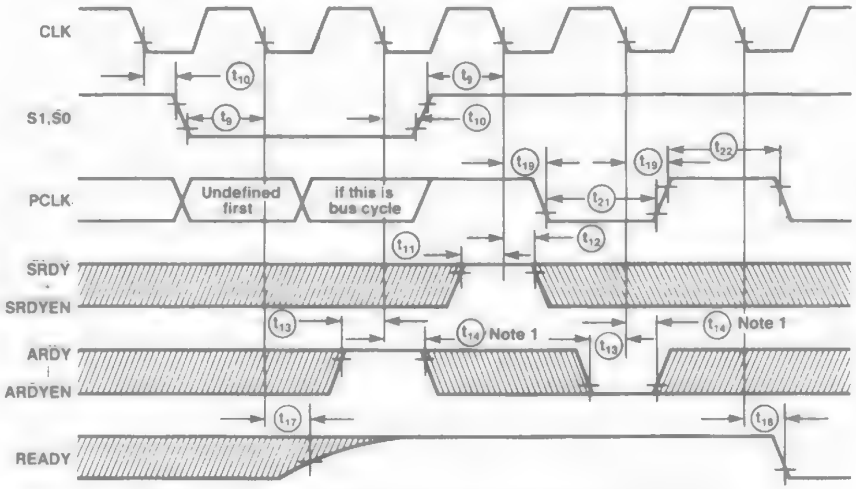
NOTE: The EFI input LOW and HIGH times as shown are required to guarentee the CLK LOW and HIGH times shown.

RESET and $\overline{\text{READY}}$ Timing as a Function of $\overline{\text{RES}}$ with $\overline{\text{S1}}$ and $\overline{\text{S0}}$ HIGH



NOTE 1: This is an asynchronous input. The setup and hold times shown are required to guarantee the response shown.

$\overline{\text{READY}}$ and PCLK Timing with $\overline{\text{RES}}$ HIGH



NOTE 1: This is an asynchronous input. The setup and hold times shown are required to guarantee the response shown.

82288
BUS CONTROLLER FOR iAPX 286 PROCESSORS

- **Provides Commands and Control for Local and System Bus**
- **Offers Wide Flexibility in System Configurations**
- **Flexible Command Timing**
- **Optional Multibus* Compatible Timing**
- **Control Drivers with 16 ma I_{OL} and 3-State Command Drivers with 32 ma I_{OL}**
- **Single +5V Supply**

The Intel 82288 Bus Controller is a 20-pin HMOS component for use in iAPX 286 microsystems. The bus controller provides command and control outputs with flexible timing options. Separate command outputs are used for memory and I/O devices. The data bus is controlled with separate data enable and direction control signals.

Two modes of operation are possible via a strapping option: Multibus compatible bus cycles, and high speed bus cycles.

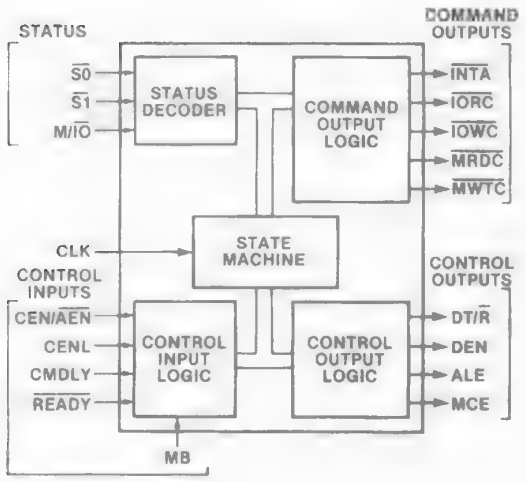


Figure 1. 82288 Block Diagram

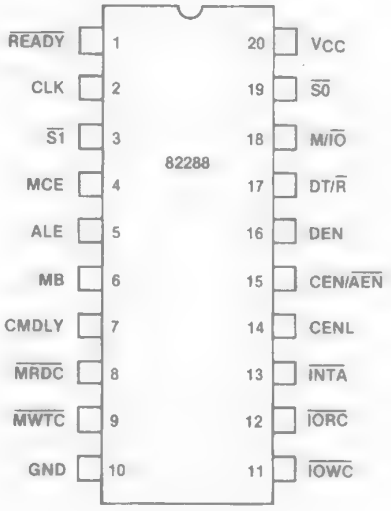


Figure 2. 82288 Pin Diagram

*Multibus is a patented bus of Intel.

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JUNE 1982
Order Number: 210471-001

Table 1. Pin Description

The following pin function descriptions are for the 82288 bus controller.

Symbol	Type	Name and Function
CLK	I	**System Clock** provides the basic timing control for the 82288 in an iAPX 286 microsystem. Its frequency is twice the internal processor clock frequency. The falling edge of this input signal establishes when inputs are sampled and command and control outputs change.
$\overline{S0}$, $\overline{S1}$	I	**Bus Cycle Status** starts a bus cycle and, along with M/$\overline{IO}$, defines the type of bus cycle. These inputs are active LOW. A bus cycle is started when either $\overline{S1}$ or $\overline{S0}$ is sampled LOW at the falling edge of CLK. These inputs have pullups sufficient to hold them HIGH when nothing drives them. Setup and hold times must be met for proper operation.

iAPX 286 Bus Cycle Status Definition

M/$\overline{IO}$	$\overline{S1}$	$\overline{S0}$	Type of Bus Cycle
0	0	0	Interrupt acknowledge
0	0	1	I/O Read
0	1	0	I/O Write
0	1	1	None; idle
1	0	0	Halt or shutdown
1	0	1	Memory read
1	1	0	Memory write
1	1	1	None; idle

M/$\overline{IO}$	I	**Memory or I/O Select** determines whether the current bus cycle is in the memory space or I/O space. When LOW, the current bus cycle is in the I/O space. Setup and hold times must be met for proper operation.
MB	I	**Multibus Mode Select** determines timing of the command and control outputs. When HIGH, the bus controller operates in Multibus mode. When LOW, the bus controller optimizes the command and control output timing for short bus cycles. The function of the CEN/$\overline{AEN}$ input pin is selected by this signal. This input is intended to be a strapping option and not dynamically changed. This input may be connected to V_{CC} or GND.
CENL	I	**Command Enable Latched** is a bus controller select signal which enables the bus controller to respond to the current bus cycle being initiated. CENL is an active HIGH input latched internally at the start of each bus cycle. CENL is used to select the appropriate bus controller for each bus cycle in a system where the CPU has more than one bus it can use. This input may be connected to V_{CC} to select this 82288 for all transfers. No control inputs affect CENL. Setup and hold times must be met for proper operation.
CMDLY	I	**Command Delay** allows delaying the start of a command. CMDLY is an active HIGH input. If sampled HIGH, the command output is not activated and CMDLY is again sampled at the next CLK cycle. When sampled LOW the selected command is enabled. If $\overline{READY}$ is detected LOW before the command output is activated, the 82288 will terminate the bus cycle, even if no command was issued. Setup and hold times must be satisfied for proper operation. This input may be connected to GND if no delays are required before starting a command.
$\overline{READY}$	I	**READY** indicates the end of the current bus cycle. $\overline{READY}$ is an active LOW input. Multibus mode requires at least one wait state to allow the command outputs to become active. $\overline{READY}$ must be LOW during reset, to force the 82288 into the idle state. Setup and hold times must be met for proper operation.

Table 1. Pin Description (Cont.)

Symbol	Type	Name and Function
CEN/$\overline{AEN}$	I	**Command Enable/Address Enable** controls the command and DEN outputs of the bus controller. CEN/$\overline{AEN}$ inputs may be asynchronous to CLK. Setup and hold times are given to assure a guaranteed response to synchronous inputs. This input may be connected to V_{CC} or GND. When MB is HIGH this pin has the $\overline{AEN}$ function. $\overline{AEN}$ is an active LOW input which indicates that the CPU has been granted use of a shared bus and the bus controller command outputs may exit 3-state OFF and become inactive (HIGH). $\overline{AEN}$ HIGH indicates that the CPU does not have control of the shared bus and forces the command outputs into 3-state OFF and DEN inactive (LOW). $\overline{AEN}$ would normally be controlled by an 82289 bus arbiter which activates $\overline{AEN}$ when that arbiter owns the bus to which the bus controller is attached. When MB is LOW this pin has the CEN function. CEN is an unlatched active HIGH input which allows the bus controller activate its command and DEN outputs. With MB LOW, CEN LOW forces the command and DEN outputs inactive but does not tristate them.
ALE	O	**Address Latch Enable** controls the address latches used to hold an address stable during a bus cycle. This control output is active HIGH. ALE will not be issued for the halt bus cycle and is not affected by any of the control inputs.
MCE	O	**Master Cascade Enable** signals that a cascade address from a master 8259A interrupt controller may be placed onto the CPU address bus for latching by the address latches under ALE control. The CPU's address bus may then be used to broadcast the cascade address to slave interrupt controllers so only one of them will respond to the interrupt acknowledge cycle. This control output is active HIGH. MCE is only active during interrupt acknowledge cycles and is not affected by any control input. Using MCE to enable cascade address drivers requires latches which save the cascade address on the falling edge of ALE.
DEN	O	**Data Enable** controls when data transceivers connected to the local data bus should be enabled. DEN is an active HIGH control output. DEN is delayed for write cycles in the Multibus mode.
DT/$\overline{R}$	O	**Data Transmit/Receive** establishes the direction of data flow to or from the local data bus. When HIGH, this control output indicates that a write bus cycle is being performed. A LOW indicates a read bus cycle. DEN is always inactive when DT/$\overline{R}$ changes states. This output is HIGH when no bus cycle is active. DT/$\overline{R}$ is not affected by any of the control inputs.
$\overline{IOWC}$	O	**I/O Write Command** instructs an I/O device to read the data on the data bus. This command output is active LOW. The MB and CMDLY inputs control when this output becomes active. $\overline{READY}$ controls when it becomes inactive.
$\overline{IORC}$	O	**I/O Read Command** instructs an I/O device to place data onto the data bus. This command output is active LOW. The MB and CMDLY inputs control when this output becomes active. $\overline{READY}$ controls when it becomes inactive.
$\overline{MWTC}$	O	**Memory Write Command** instructs a memory device to read the data on the data bus. This command output is active LOW. The MB and CMDLY inputs control when this output becomes active. $\overline{READY}$ controls when it becomes inactive.
$\overline{MRDC}$	O	**Memory Read Command** instructs the memory device to place data onto the data bus. This command output is active LOW. The MB and CMDLY inputs control when this output becomes active. $\overline{READY}$ controls when it becomes inactive.
$\overline{INTA}$	O	**Interrupt Acknowledge** tells an interrupting device that its interrupt request is being acknowledged. This command output is active LOW. The MB and CMDLY inputs control when this output becomes active. $\overline{READY}$ controls when it becomes inactive.
V_{CC}		**System Power:** +5V power supply
GND		**System Ground:** 0 volts

FUNCTIONAL DESCRIPTION

Introduction

The 82288 bus controller is used in iAPX 286 systems to provide address latch control, data transceiver control, and standard level-type command outputs. The command outputs are timed and have sufficient drive capabilities for large TTL buses and meet all IEEE-796 requirements for Multibus. A special Multibus mode is provided to statisfy all address/data setup and hold time requirements. Command timing may be tailored to special needs via a CMDLY input to determine the start of a command and $\overline{\text{READY}}$ to determine the end of a command.

Connection to multiple buses are supported with a latched enable input (CENL). An address decoder can determine which, if any, bus controller should be enabled for the bus cycle. This input is latched to allow an address decoder to take full advantage of the pipelined timing on the iAPX 286 local bus.

Buses shared by several bus controllers are supported. An $\overline{\text{AEN}}$ input prevents the bus controller from driving the shared bus command and data signals except when enabled by an external bus arbiter such as the 82289.

Separate DEN and DT/$\overline{\text{R}}$ outputs control the data transceivers for all buses. Bus contention is eliminated by disabling DEN before changing DT/$\overline{\text{R}}$. The DEN timing allows sufficient time for tristate bus drivers to enter 3-state OFF before enabling other drivers onto the same bus.

The term CPU refers to any iAPX 286 processor or iAPX 286 support component which may become an iAPX 286 local bus master and thereby drive the 82288 status inputs.

Processor Cycle Definition

Any CPU which drives the local bus uses an internal clock which is one half the frequency of the system clock (CLK) (see Figure 3). Knowledge of the phase of the local bus master internal clock is required for proper operation of the iAPX 286 local bus. The local bus master informs the bus controller of its internal clock phase when it asserts the status signals. Status signals are always asserted in Phase 1 of the local bus master's internal clock.

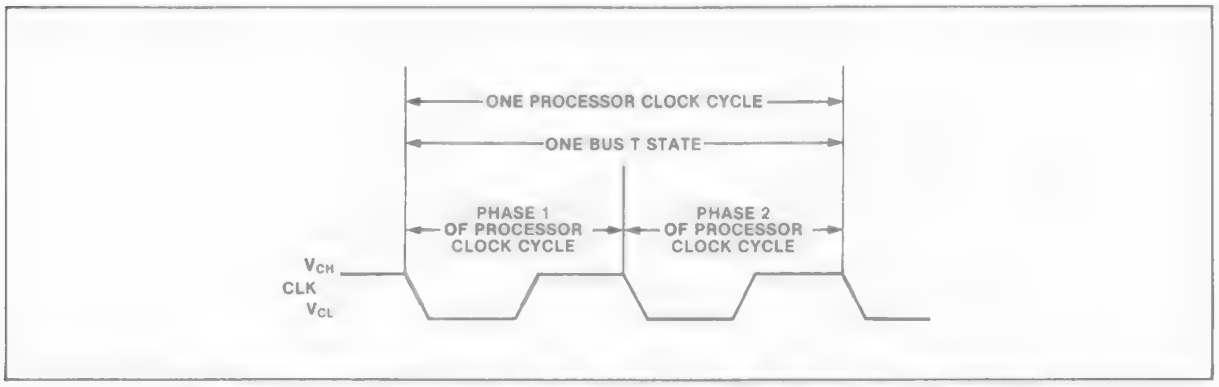

Figure 3. CLK Relationship to the Processor Clock and Bus T-States

Bus State Definition

The 82288 bus controller has three bus states (see Figure 4): Idle (T_I) Status (T_S) and Command (T_C). Each bus state is two CLK cycles long. Bus state phases correspond to the internal CPU processor clock phases.

The T_I bus state occurs when no bus cycle is currently active on the iAPX 286 local bus. This state may be repeated indefinitely. When control of the local bus is being passed between masters, the bus remains in the T_I state.

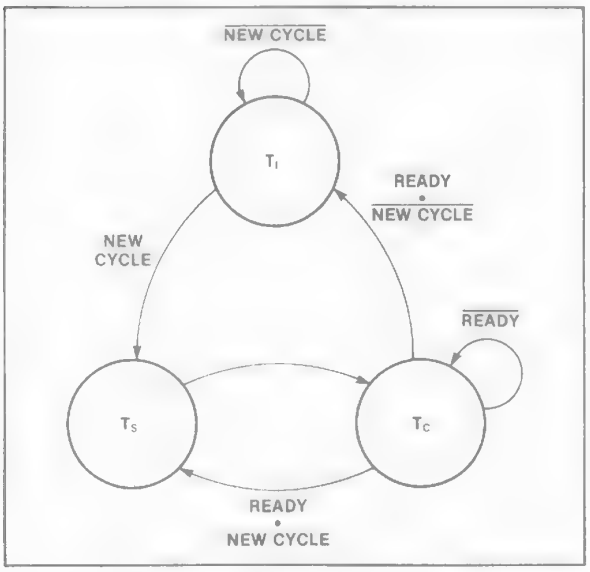

Figure 4. 82288 Bus States

Bus Cycle Definition

The $\overline{S1}$ and $\overline{S0}$ inputs signal the start of a bus cycle. When either input becomes LOW, a bus cycle is started. The T_S bus state is defined to be the two CLK cycles during which either $\overline{S1}$ or $\overline{S0}$ are active (see Figure 5). These inputs are sampled by the 82288 at every falling edge of CLK. When either $\overline{S1}$ or $\overline{S0}$ are sampled LOW, the next CLK cycle is considered the second phase of the internal CPU clock cycle.

The local bus enters the T_C bus state after the T_S state. The shortest bus cycle may have one T_S state and one T_C state. Longer bus cycles are formed by repeating T_C states. A repeated T_C bus state is called a wait state.

The $\overline{READY}$ input determines whether the current T_C bus state is to be repeated. The $\overline{READY}$ input has the same timing and effect for all bus cycles. $\overline{READY}$ is sampled at the end of each T_C bus state to see if it is active. If sampled HIGH, the T_C bus state is repeated. This is called inserting a wait state. The control and command outputs do not change during wait states.

When $\overline{READY}$ is sampled LOW, the current bus cycle is terminated. Note that the bus controller may enter the T_S bus state directly from T_C if the status lines are sampled active at the next falling edge of CLK.

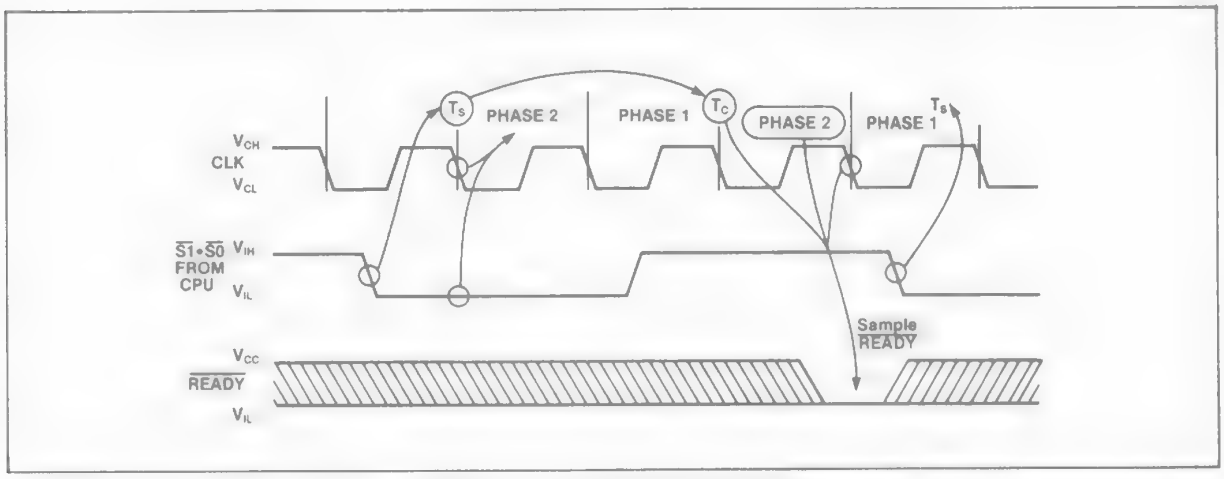

Figure 5. Bus Cycle Definition

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Table 2. Command and Control Outputs for Each Type of Bus Cycle

Type of Bus Cycle	M/$\overline{IO}$	$\overline{S1}$	$\overline{S0}$	Command Activated	DT/$\overline{R}$ State	ALE, DEN Issued?	MCE Issued?
Interrupt Acknowledge	0	0	0	$\overline{INTA}$	LOW	YES	YES
I/O Read	0	0	1	$\overline{IORC}$	LOW	YES	NO
I/O Write	0	1	0	$\overline{IOWC}$	HIGH	YES	NO
None; idle	0	1	1	None	HIGH	NO	NO
Halt/Shutdown	1	0	0	None	HIGH	NO	NO
Memory Read	1	0	1	$\overline{MRDC}$	LOW	YES	NO
Memory Write	1	1	0	$\overline{MWTC}$	HIGH	YES	NO
None; idle	1	1	1	None	HIGH	NO	NO

Operating Modes

Two types of buses are supported by the 82288: Multibus and non-Multibus. When the MB input is strapped HIGH, Multibus timing is used. In Multibus mode, the 82288 delays command and data activation to meet IEEE-796 requirements on address to command active and write data to command active setup timing. Multibus mode requires at least one wait state in the bus cycle since the command outputs are delayed. The non-Multibus mode does not delay any outputs and does not require wait states. The MB input affects the timing of the command and DEN outputs.

Command and Control Outputs

The type of bus cycle performed by the local bus master is encoded in the M/$\overline{IO}$, $\overline{S1}$, and $\overline{S0}$ inputs. Different command and control outputs are activated depending on the type of bus cycle. Table 2 indicates the cycle decode done by the 82288 and the effect on command, DT/$\overline{R}$, ALE, DEN, and MCE outputs.

Bus cycles come in three forms: read, write, and halt. Read bus cycles include memory read, I/O read, and interrupt acknowledge. The timing of the associated read command outputs ($\overline{MRDC}$, $\overline{IORC}$, and $\overline{INTA}$), control outputs (ALE, DEN, DT/$\overline{R}$) and control inputs (CEN/$\overline{AEN}$, CENL, CMDLY, MB, and $\overline{READY}$) are identical for all read bus cycles. Read cycles differ only in which command output is activated. The MCE control output is only asserted during interrupt acknowledge cycles.

Write bus cycles activate different control and command outputs with different timing than read bus cycles. Memory write and I/O write are write bus cycles whose timing for command outputs ($\overline{MWTC}$ and $\overline{IOWC}$), control outputs (ALE, DEN, DT/$\overline{R}$) and control inputs (CEN/$\overline{AEN}$, CENL, CMDLY, MB, and $\overline{READY}$) are identical. They differ only in which command output is activated.

Halt bus cycles are different because no command or control output is activated. All control inputs are ignored until the next bus cycle is started via $\overline{S1}$ and $\overline{S0}$.

Figures 6-10 show the basic command and control output timing for read and write bus cycles. Halt bus cycles are not shown since they activate no outputs. The basic idle-read-idle and idle-write-idle bus cycles are shown. The signal label CMD represents the appropriate command output for the bus cycle. For Figures 6-10, the CMDLY input is connected to GND and CENL to V_{CC}. The effects of CENL and CMDLY are described later in the section on control inputs.

Figures 6 and 7 show non-Multibus cycles. MB is connected to GND while CEN is connected to V_{CC}. Figure 6 shows a read cycle with no wait states while Figure 7 shows a write cycle with one wait state. The $\overline{READY}$ input is shown to illustrate how wait states are added.

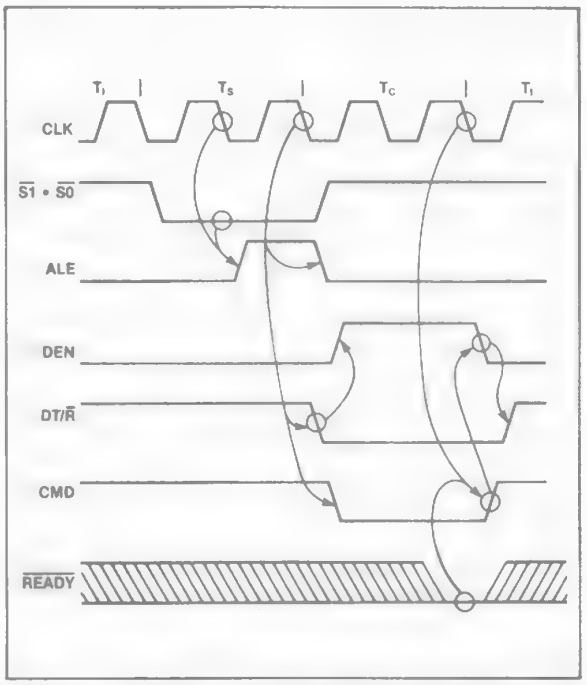

Figure 6. Idle-Read-Idle Bus Cycles with MB = 0

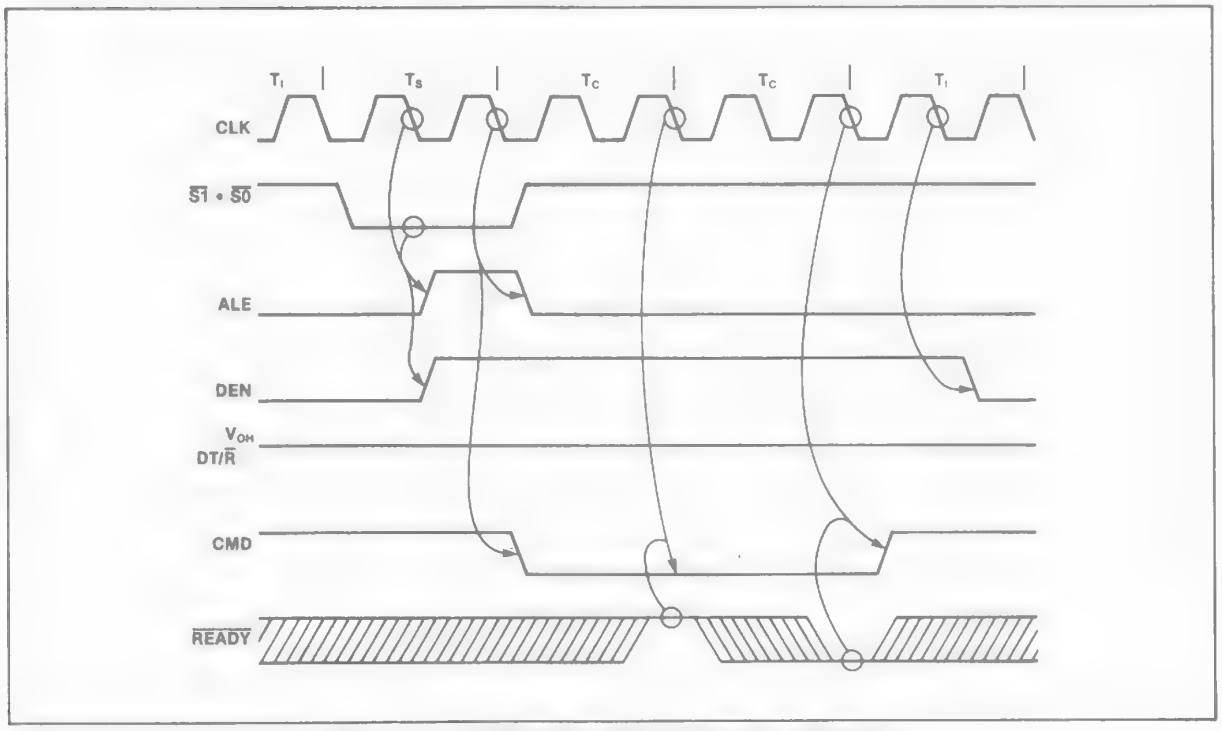

Figure 7. Idle-Write-Idle Bus Cycles with MB = 0

Bus cycles can occur back to back with no T_I bus states between T_C and T_S. Back to back cycles do not affect the timing of the command and control outputs. Command and control outputs always reach the states shown for the same clock edge (within T_S, T_C, or following bus state) of a bus cycle.

A special case in control timing occurs for back to back write cycles with MB = 0. In this case, DT/$\overline{R}$ and DEN remain HIGH between the bus cycles (see Figure 8). The command and ALE output timing does not change.

Figures 9 and 10 show a Multibus cycle with MB = 1. $\overline{AEN}$ and CMDLY are connected to GND. The effects of CMDLY and $\overline{AEN}$ are described later in the section on control inputs. Figure 9 shows a read cycle with one wait state and Figure 10 shows a write cycle with two wait states. The second wait state of the write cycle is shown only for example purposes and is not required. The $\overline{READY}$ input is shown to illustrate how wait states are added.

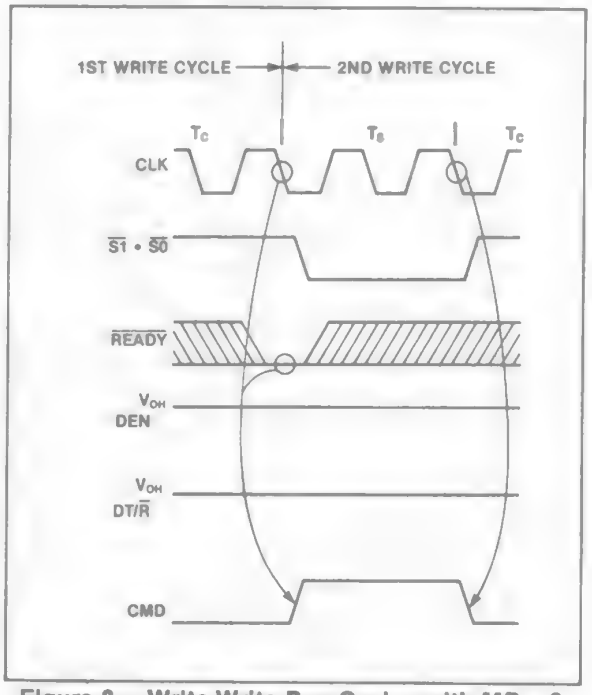

Figure 8. Write-Write Bus Cycles with MB = 0

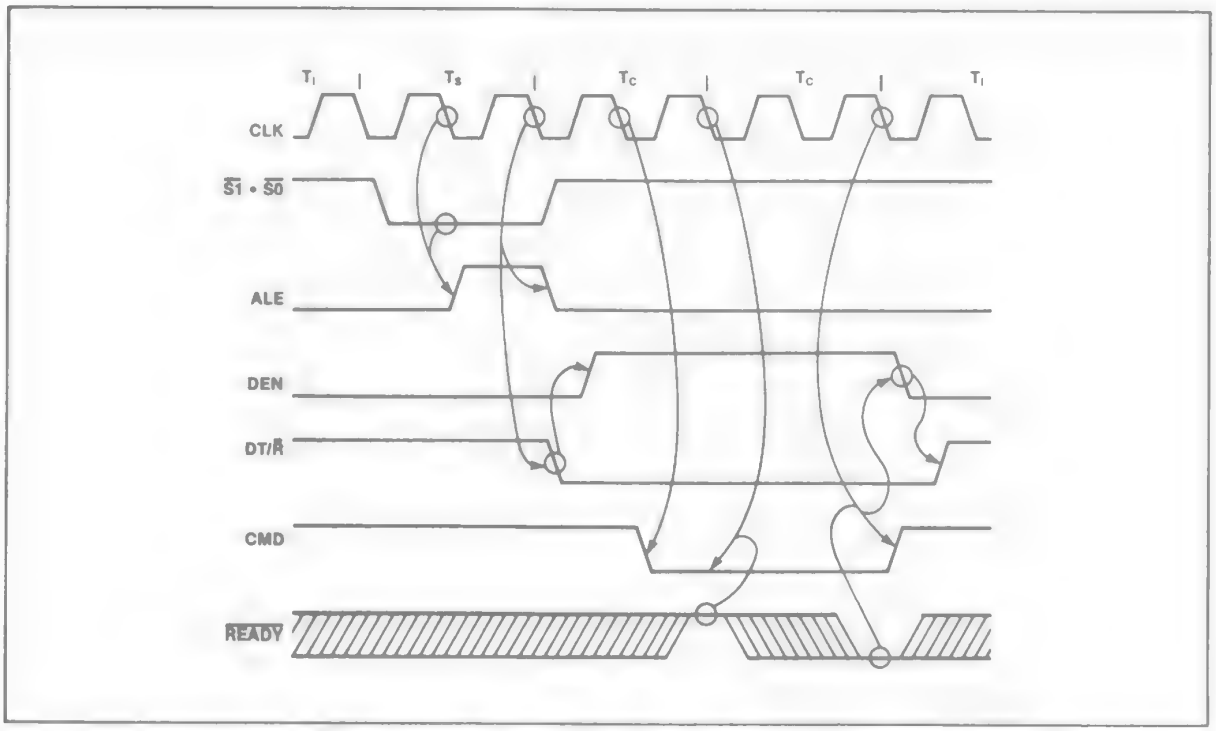

Figure 9. Idle-Read-Idle Bus Cycles with MB = 1

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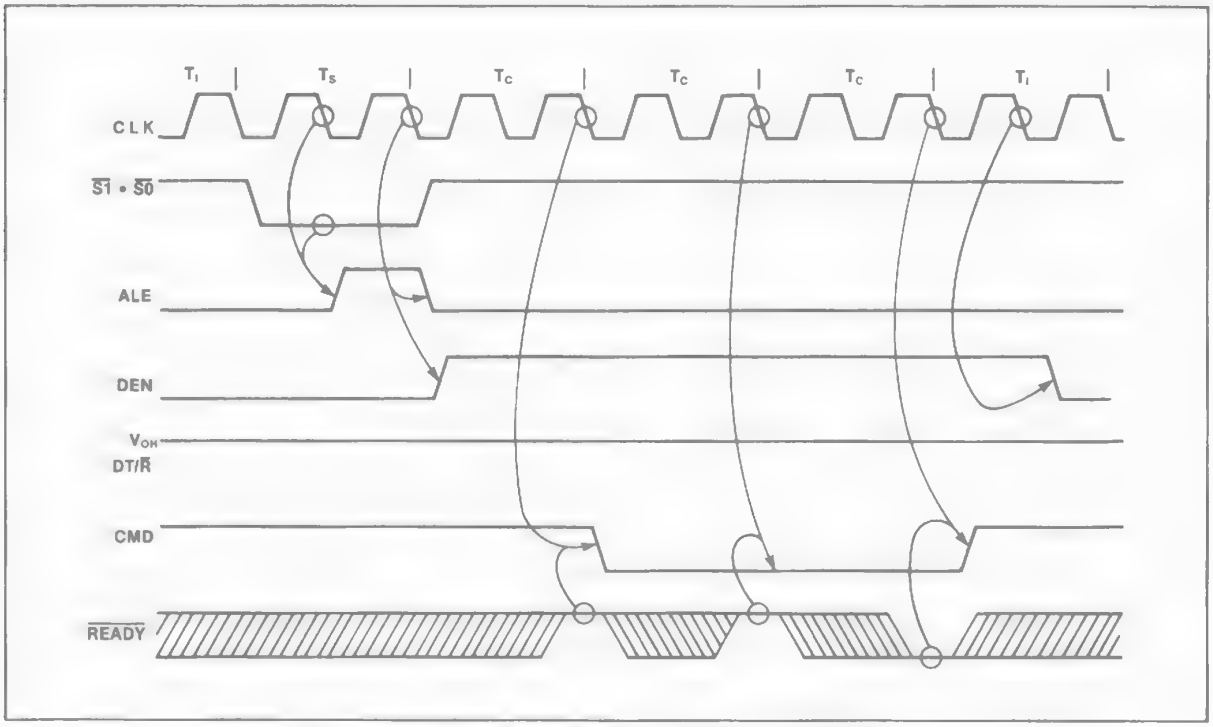

Figure 10. Idle-Write-Idle Bus Cycles with MB = 1

The MB control input affects the timing of the command and DEN outputs. These outputs are automatically delayed in Multibus mode to satisfy three requirements:

1) 50 ns minimum setup time for valid address before any command output becomes active.

2) 50 ns minimum setup time for valid write data before any write command output becomes active.

3) 65 ns maximum time from when any read command becomes inactive until the slave's read data drivers reach 3-state OFF.

Three signal transitions are delayed by MB = 1 as compared to MB = 0:

1) The HIGH to LOW transition of the read command outputs ($\overline{IORC}$, $\overline{MRDC}$, and $\overline{INTA}$) are delayed one CLK cycle.

2) The HIGH to LOW transition of the write command outputs ($\overline{IOWC}$ and $\overline{MWTC}$) are delayed two CLK cycles.

3) The LOW to HIGH transition of DEN for write cycles is delayed one CLK cycle.

Back to back bus cycles with MB = 1 do not change the timing of any of the command or control outputs. DEN always becomes inactive between bus cycles with MB = 1.

Except for a halt or shutdown bus cycle, ALE will be issued during the second half of T_S for any bus cycle. ALE becomes inactive at the end of the T_S to allow latching the address to keep it stable during the entire bus cycle. The address outputs may change during Phase 2 of any T_C bus state. ALE is not affected by any control input.

Figure 11 shows how MCE is timed during interrupt acknowledge (INTA) bus cycles. MCE is one CLK cycle longer than ALE to hold the cascade address from a master 8259A valid after the falling edge of ALE. With the exception of the MCE control output, an INTA bus cycle is identical in timing to a read bus cycle. MCE is not affected by any control input.

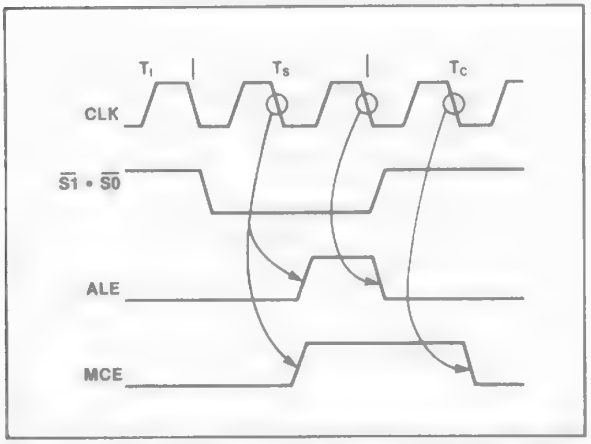

Figure 11. MCE Operation for an INTA Bus Cycle

Control Inputs

The control inputs can alter the basic timing of command outputs, allow interfacing to multiple buses, and share a bus between different masters. For many iAPX 286 systems, each CPU will have more than one bus which may be used to perform a bus cycle. Normally, a CPU will only have one bus controller active for each bus cycle. Some buses may be shared by more than one CPU (i.e. Multibus) requiring only one of them use the bus at a time.

Systems with multiple and shared buses use two control input signals of the 82288 bus controller, CENL and $\overline{AEN}$ (see Figure 12). CENL enables the bus controller to control the current bus cycle. The $\overline{AEN}$ input prevents a bus controller from driving its command outputs. $\overline{AEN}$ HIGH means that another bus controller may be driving the shared bus.

In Figure 12, two buses are shown: a local bus and a Multibus. Only one bus is used for each CPU bus cycle. The CENL inputs of the bus controllers select which bus controller is to perform the bus cycle. An address decoder determines which bus to use for each bus cycle. The 82288 connected to the shared Multibus must be selected by CENL and be given access to the Multibus by $\overline{AEN}$ before it will begin a Multibus operation.

CENL must be sampled HIGH at the end of the T_S bus state (see waveforms) to enable the bus controller to activate its command and control outputs. If sampled LOW the commands and DEN will not go active and DT/$\overline{R}$ will remain HIGH. The bus controller will ignore the CMDLY, CEN, and $\overline{READY}$ inputs until another bus cycle is started via $\overline{S1}$ and $\overline{S0}$. Since an address decoder is commonly used to identify which bus is required for each bus cycle, CENL is latched to avoid the need for latching its input.

The CENL input can affect the DEN control output. When MB = 0, DEN normally becomes active during Phase 2 of T_S in write bus cycles. This transition occurs before CENL is sampled. If CENL is sampled LOW, the DEN output will be forced LOW during T_C as shown in the timing waveforms.

When MB = 1, CEN/$\overline{AEN}$ becomes $\overline{AEN}$. $\overline{AEN}$ controls when the bus controller command outputs enter and exit 3-state OFF. $\overline{AEN}$ is intended to be driven by a bus arbiter, like the 82289, which assures only one bus controller is driving the shared bus at any time. When $\overline{AEN}$ makes a LOW to HIGH transition, the command outputs immediately enter 3-state OFF and DEN is forced inactive. An inactive DEN should force the local data transceivers connected to the shared data bus into 3-state OFF (see Figure 12). The LOW to HIGH transition of $\overline{AEN}$ should only occur during T_I or T_S bus states.

The HIGH to LOW transition of $\overline{AEN}$ signals that the bus controller may now drive the shared bus command signals. Since a bus cycle may be active or be in the process of starting, $\overline{AEN}$ can become active during any T-state. $\overline{AEN}$ LOW immediately allows DEN to go to the appropriate state. Three CLK edges later, the command outputs will go active (see timing waveforms). The Multibus requires this delay for the address and data to be valid on the bus before the commands become active.

When MB = 0, CEN/$\overline{AEN}$ becomes CEN. CEN is an asynchronous input which immediately affects the command and DEN outputs. When CEN makes a HIGH to LOW transition, the commands

and DEN are immediately forced inactive. When CEN makes a LOW to HIGH transition, the commands and DEN outputs immediately go to the appropriate state (see timing waveforms). $\overline{\text{READY}}$ must still become active to terminate a bus cycle if CEN remains LOW for a selected bus controller (CENL was latched HIGH).

Some memory or I/O systems may require more address or write data setup time to command active than provided by the basic command output timing. To provide flexible command timing, the CMDLY input can delay the activation of command outputs. The CMDLY input must be sampled LOW to activate the command outputs. CMDLY does not affect the control outputs ALE, MCE, DEN, and DT/$\overline{\text{R}}$.

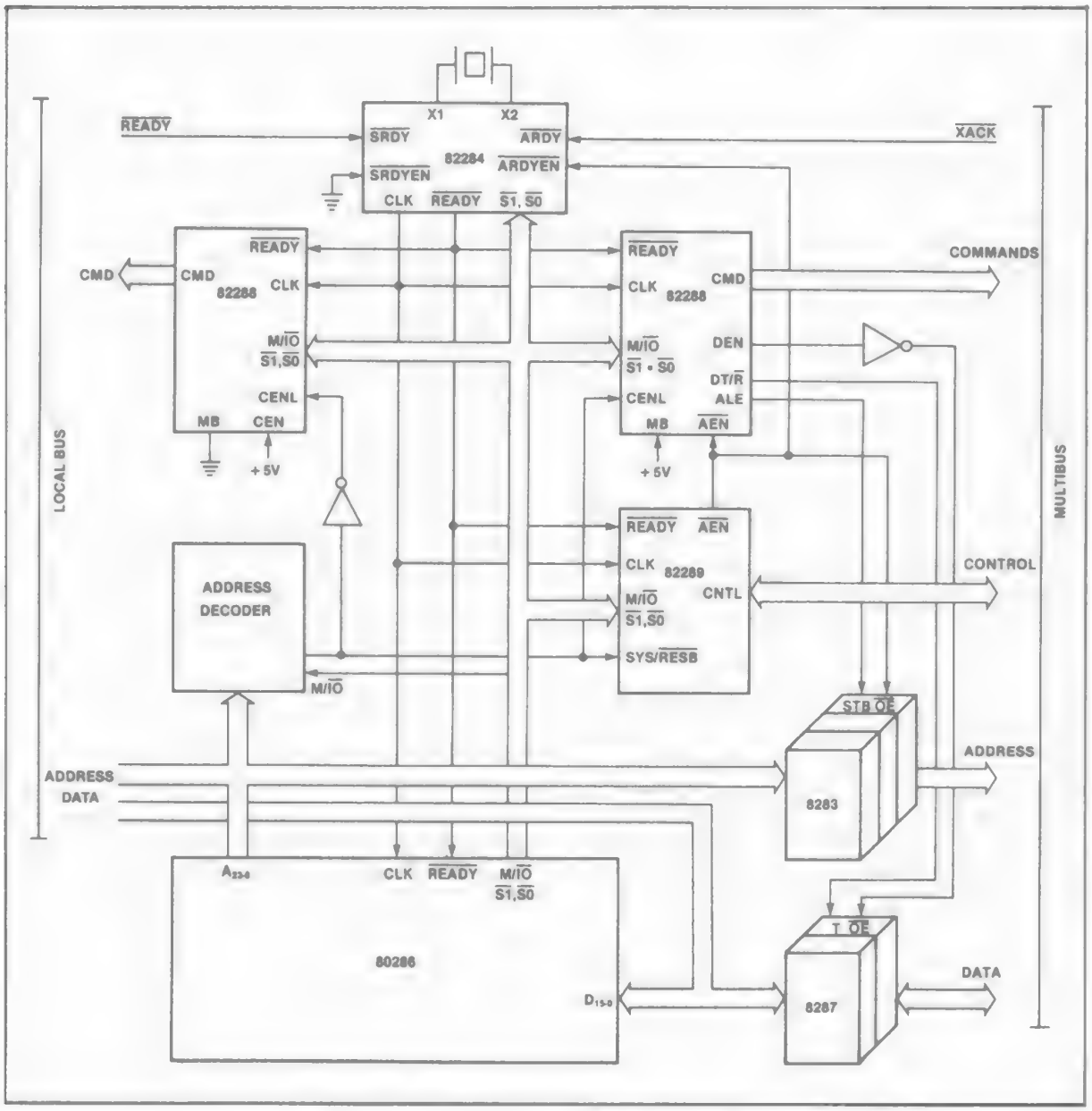

Figure 12. System Use of $\overline{\text{AEN}}$ and CENL

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CMDLY is first sampled on the falling edge of the CLK ending T_S. If sampled HIGH, the command output is not activated, and CMDLY is again sampled on the next falling edge of CLK. Once sampled LOW, the proper command output becomes active immediately if MB = 0. If MB = 1, the proper command goes active no earlier than shown in Figures 9 and 10.

$\overline{\text{READY}}$ can terminate a bus cycle before CMDLY allows a command to be issued. In this case no commands are issued and the bus controller will deactivate DEN and DT/$\overline{\text{R}}$ in the same manner as if a command had been issued.

Waveforms Discussion

The waveforms show the timing relationships of inputs and outputs and do not show all possible transitions of all signals in all modes. Instead, all signal timing relationships are shown via the general cases. Special cases are shown when needed. The waveforms provide some functional descriptions of the 82288; however, most functional descriptions are provided in Figures 5 through 11.

To find the timing specification for a signal transition in a particular mode, first look for a special case in the waveforms. If no special case applies, then use a timing specification for the same or related function in another mode.

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias....0°C to 70°C
Storage Temperature.....−65°C to +150°C
Voltage on Any Pin with
Respect to GND.....−0.5V to +7V
Power Dissipation.....1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (V_{CC} = 5V ± 10%, T_A = 0°C to 70°C)

Symbol	Parameter	Min	Max	Units	Test Conditions
I_{CC}	Power Supply Current		100	mA	
I_F	Forward Input Current				
	CLK Input		−1	mA	V_F = 0.45V
	Other Inputs		−.5	mA	V_F = 0.45V
I_R	Reverse Input Current		50	uA	$V_R = V_{CC}$
V_{OL}	Output LOW Voltage				
	Command Outputs		.45	V	I_{OL} = 32 mA
	Control Outputs		.45	V	I_{OL} = 16mA
V_{OH}	Output HIGH Voltage				
	Command Outputs	2.4		V	I_{OH} = −5 mA
	Control Outputs	2.4		V	I_{OH} = −1 mA
V_{IL}	Input LOW Voltage	−0.5	.8	V	
V_{CL}	CLK Input LOW Voltage	−0.5	.6	V	
V_{IH}	Input HIGH Voltage	2.0	V_{CC} + 0.5	V	
V_{CH}	CLK Input HIGH Voltage	3.9	V_{CC} + 0.5	V	
I_{OFF}	Output Off Current		100	uA	
C_{CLK}	CLK Input Capacitance		10	pF	
C_I	Input Capacitance		10	pF	

A.C. CHARACTERISTICS (V_{CC} = 5V ± 10%, T_A = 0°C to 70°C)

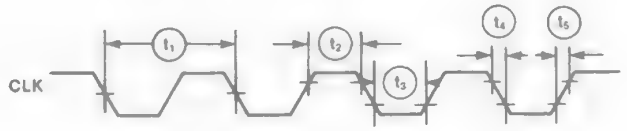
Symbol	Parameter	Min	Max	Units	Test Conditions
t_1	CLK Period	62.5	250	ns	at 1.5V
t_2	CLK HIGH Time	20	235	ns	at 3.9V
t_3	CLK LOW Time	15	230	ns	at 0.6V
t_4	CLK Fall Time		10	ns	3.5V to 1.0V
t_5	CLK Rise Time		10	ns	1.0V to 3.5V
t_6	M/$\overline{IO}$ and Status Setup Time	22.5		ns	From 0.8V or 2.0V on input to 0.8V on CLK
t_7	M/$\overline{IO}$ and Status Hold Time	0		ns	
t_8	CENL Setup Time	20		ns	
t_9	CENL Hold Time	0		ns	
t_{10}	$\overline{READY}$ Setup Time	38.5		ns	
t_{11}	$\overline{READY}$ Hold Time	25		ns	
t_{12}	CMDLY Setup Time	20		ns	
t_{13}	CMDLY Hold Time	0		ns	
t_{14}	$\overline{AEN}$ Setup Time	25		ns	Note 1
t_{15}	$\overline{AEN}$ Hold Time	0		ns	Note 1
t_{16}	ALE, MCE Active Delay	3	15	ns	From 0.8V on CLK to 0.8V or 2.0V on output; I_{OL} = 16 ma, I_{OH} = −1 ma, C_L = 150 pF
t_{17}	ALE, MCE Inactive Delay		20	ns	
t_{18}	DEN (WRITE) Inactive From CENL		35	ns	
t_{19}	DT/$\overline{R}$ LOW From CLK		20	ns	
t_{20}	DEN (READ) Active From DT/$\overline{R}$	10	50	ns	
t_{21}	DEN (READ) Inactive Delay	3	15	ns	
t_{22}	DT/$\overline{R}$ HIGH From DEN Inactive	10	40	ns	
t_{23}	DEN (WRITE) Active Delay		30	ns	
t_{24}	DEN (WRITE) Inactive Delay	3	30	ns	
t_{25}	DEN Inactive From CEN		25	ns	
t_{26}	DEN Active From CEN		25	ns	
t_{27}	DT/$\overline{R}$ HIGH From CLK And CEN		50	ns	Note 2
t_{28}	DEN Active From $\overline{AEN}$		30	ns	I_{OL} = 32 ma, I_{OH} = −5 ma, C_L = 300 pF, From 0.8V on CLK to 0.8V or 2.0V on output
t_{29}	Command Active Delay	3	20	ns	
t_{30}	Command Inactive Delay	3	15	ns	
t_{31}	Command Inactive From CEN		25	ns	
t_{32}	Command Active From CEN		25	ns	
t_{33}	Command Inactive Enable From $\overline{AEN}$		40	ns	
t_{34}	Command Float Time		40	ns	

Note 1: $\overline{AEN}$ is a asynchronous input. $\overline{AEN}$ setup and hold time is specified to guarantee the response shown in the waveforms.

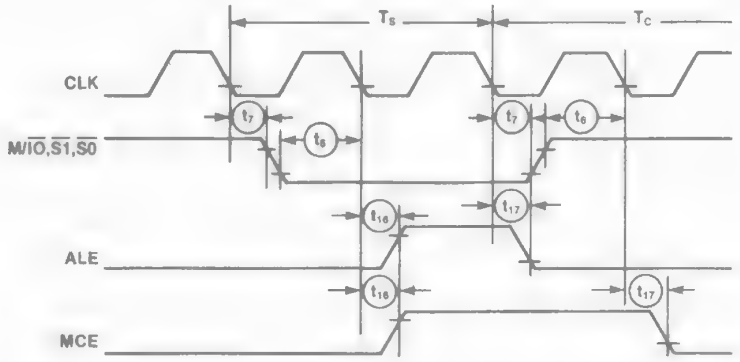
Note 2: T_{27} only applies to bus cycles where MB = 0, the 82288 was selected, and DEN = 0 when the cycle terminated (because CEN = 0).

WAVEFORMS

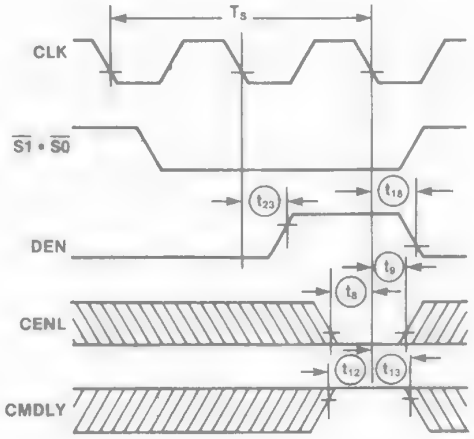
CLK CHARACTERISTICS



STATUS, ALE, MCE, CHARACTERISTICS



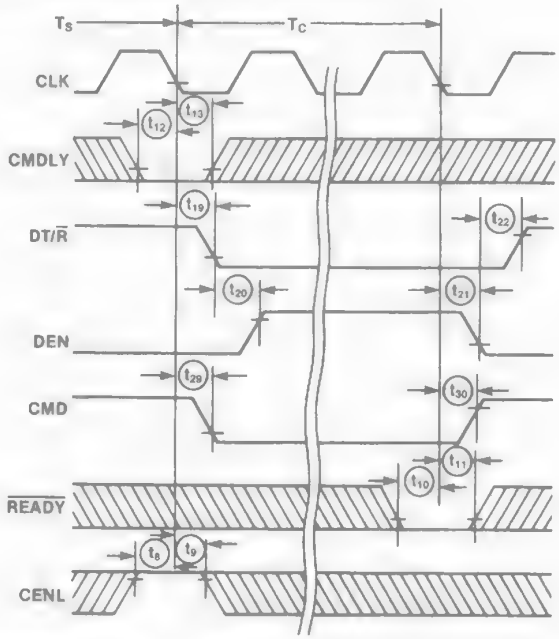
CENL, CMDLY, DEN CHARACTERISTICS WITH MB = 0 AND CEN = 1 DURING WRITE CYCLE



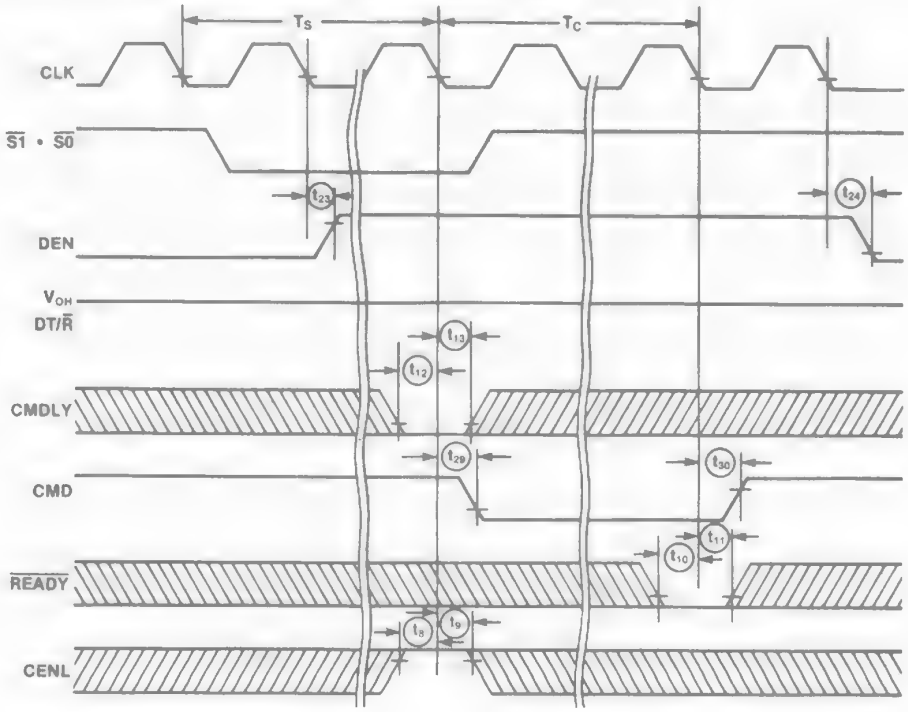
AFN-00787A

WAVEFORMS (Continued)

READ CYCLE CHARACTERISTICS WITH MB = 0 AND CEN = 1



WRITE CYCLE CHARACTERISTICS WITH MB = 0 AND CEN = 1



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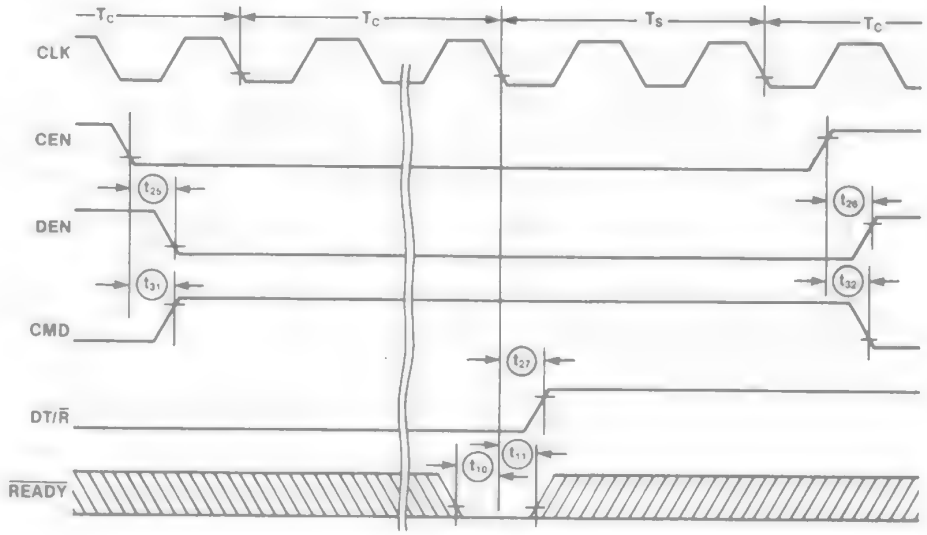
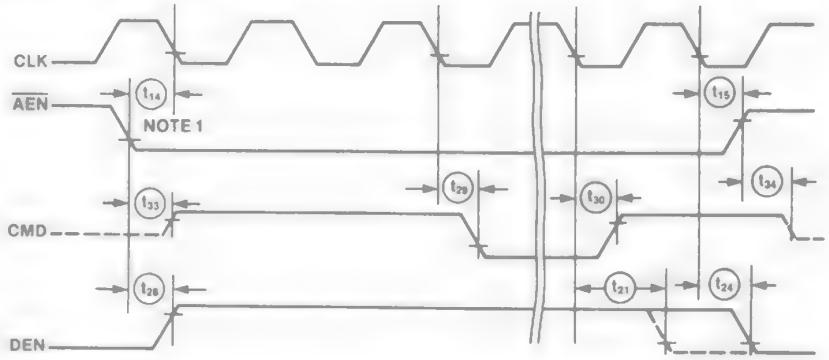
WAVEFORMS (Continued)

CEN CHARACTERISTICS WITH MB = 0



$\overline{AEN}$ CHARACTERISTICS WITH MB = 1



NOTE 1: $\overline{AEN}$ is an asynchronous input. $\overline{AEN}$ setup and hold time is specified to guarantee the response shown in the waveforms.

iAPX 432 Micromainframe™

5

Additional 432 Literature

Additional data sheets on the 432 are available free of charge from the Intel Literature Department. They include:

iAPX 43201/43202 VLSI General Data Processor Data Sheet (Order Number 590125)
iAPX 43203 VLSI Interface Processor Data Sheet (Order Number 590130)
Tentime-Timesharing Services for Developing iAPX 432 Software Data Sheet (Order Number 172464)
Intel 432 Cross Development System Data Sheet (Order Number 171868)
System 432/600 32-Bit Extensible Computer System Data Sheet (Order Number 590135)
Intel iAPX 432 Systems Design Course (Order Number 210785)
iMax 432 Multifunction Applications Executive (Order Number 172087)
Unix-Compatible Software for Intel 432 Cross Development System (Order Number 172466)

PRELIMINARY

iAPX 43201/43202/43203 VLSI MICROMAINFRAME™ SYSTEM

- Multiprocessor Computer System provides a range of performance
- Object Based Architecture Meets Operating System and High Level Language Needs
- 2^{40} Bytes of Virtual Address Space
- Protected Addressing increases reliability and fits High Level Language Needs
- Multiple I/O Subsystems provide I/O Extensibility
- Silicon O.S. Provides:
  - — Transparent Multiprocessor Support
  - — Multitasking
  - — Dynamic Storage Allocation/Deallocation
  - — Interprocess Communication

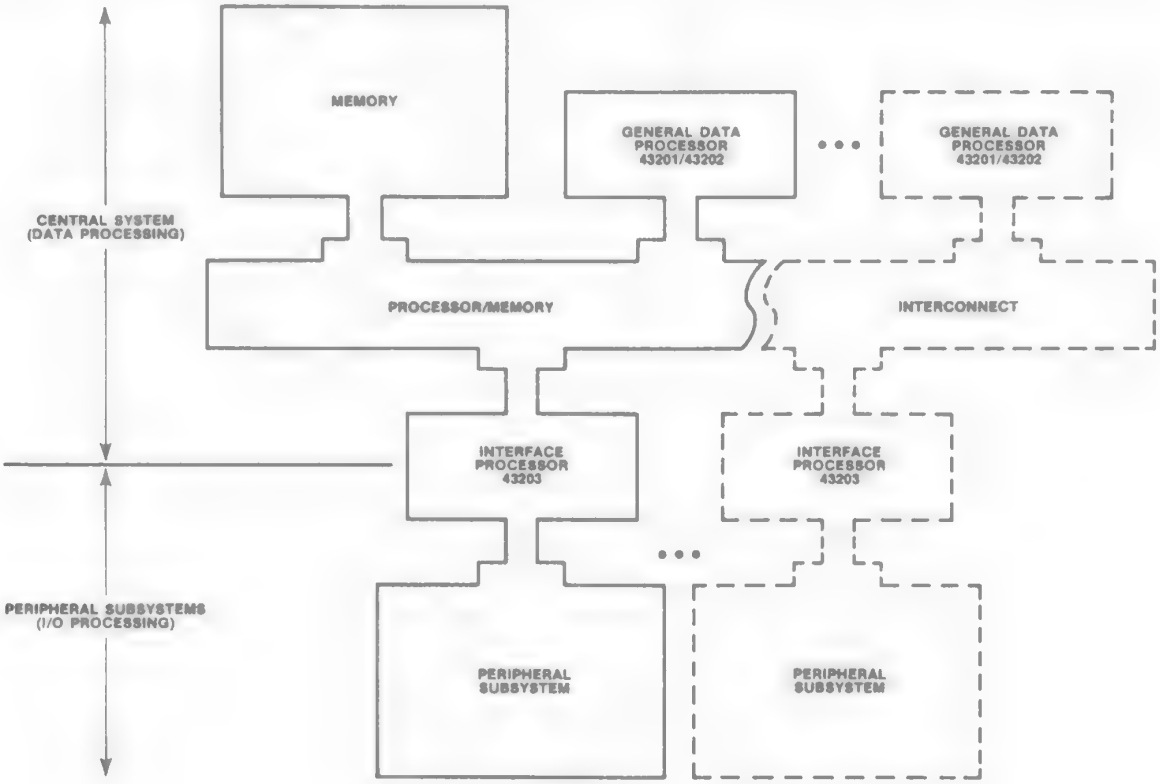


Figure 1. General 432 System Organization

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APPLICATIONS

The 432 is a VLSI computer system aimed at a distinctive class of applications. Products well-suited to the 432 exhibit some or all of the following attributes (as seen by the OEM, not the end user):

- a *range of performance* (potentially extending up to the level of a midrange mainframe) is required to span a family of related products or to provide headroom for future growth;
- *maximum dependability* (data integrity and uptime) of both hardware and software is critical;
- *software dominates* development cost and time to market;
- *concurrent execution* of many independent and cooperative activities characterizes the run-time environment;
- *growth and evolution* of services over time make software revision as important as initial development.

Compared to "traditional" microcomputer applications, these applications are larger (as measured by consumption of computer as well as staff and financial resources) and are far more complex. These factors place demanding requirements on the computer system selected to support the application.

The goal of the 432 is to significantly reduce the lifecycle costs of complex applications. Toward this end, the 432 introduces a *new computer technology*, an integrated system of hardware, software and methodology.

SYSTEM ORGANIZATION

All 432-based systems share the overall organization depicted in figure 1. The boundary between the central system and the peripheral subsystems essentially divides responsibility for data processing from input/output processing. It also serves as a protective barrier: all information in central system memory is shielded (by 432 hardware) against unauthorized access; peripheral subsystems may or may not provide any sort of protection. Finally, processing required to satisfy a critical real-time constraint (usually related to an I/O device) is generally performed in a peripheral subsystem, close to the source of the constraint.

The central system is organized as a set of 432 processors that share access to a common pool of memory and to each other. General data processors (GDPs) perform computational work, while interface processors (IPs) provide pathways for input/output to and from the central memory. The number and type of processors configured in a given system is a function of performance requirements, and can be varied independently of software. All 432 processors have built-in facilities for communicating with each other, both automatically and under software control. Additional communication facilities permit programs running on the same or different processors to exchange messages through memory.

The central system supports up to 2^{24} bytes (16 megabytes) of real memory, and a virtual memory space of 2^{40} (over a trillion) bytes. Enforced automatically by the processors, every data structure in the central memory is individually protected. It is important to note here that "data structure" means *any organized collection of information*, including such logical entities as operand stacks and sequences of code, as well as what are ordinarily considered data structures.

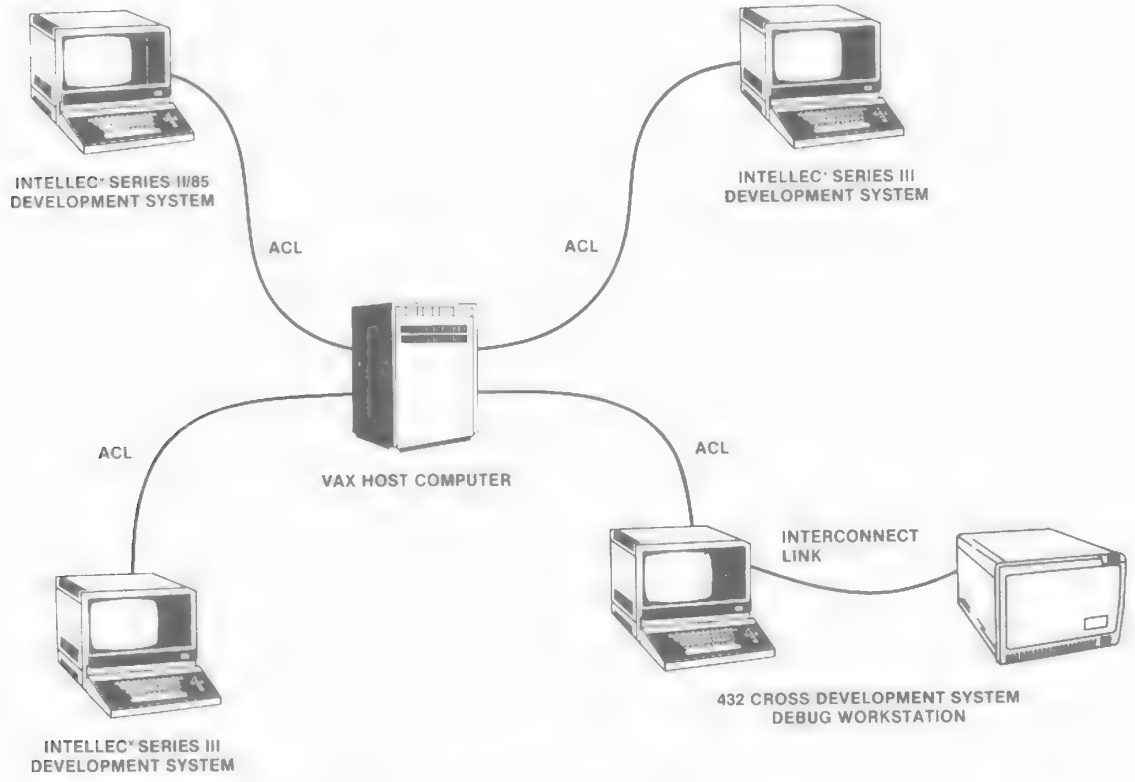
A multiprocessor design like the 432 permits widely differing systems to be built from a small collection of parts. No bus design could possibly satisfy the cost, size, flexibility and performance requirements of all possible system configurations. Therefore, the 432 defines a standard processor/memory communications *protocol* rather than a standard bus. Designed to minimize bus occupancy and exploit available bus width, the protocol is based on a variable-length (1 to 16 byte) *packet* of information. Processors transmit request packets to memory, and receive reply packets in response to read operations. The protocol defines interprocessor communication as well. Each application is free to design an interconnect structure that implements the protocol in conformance with local needs.

Independent decentralized I/O, along the lines of the mainframe channel concept, is inherent in the 432. Input/output operations — including all device control, interrupt handling and data buffering — are delegated to peripheral subsystems. These are autonomous satellite computers attached to the central system by means of 432 interface processors. The number and configuration of peripheral subsystems is a function of application needs and can evolve over time. Any computer that can communicate over a standard 8- or 16-bit bus, such as Intel's Multibus design (IEEE standard 769), can serve as a peripheral subsystem.

INTEL ASYNCHRONOUS COMMUNICATIONS LINK

- **Communications software for VAX* host computer and Intel microcomputer development systems**
- **Compatible with VAX/VMS* and UNIX† operating systems**
- **Supports Intel's Model 800, Intellec® Series II, and Series III microcomputer development systems**
- **Allows development system console to function as a host terminal**
- **Operates through direct cable connection or over telephone lines**
- **Software selectable transmission rate from 300 to 9600 baud**
- **Links host and debug workstation in the 432 Cross Development System**

Intel's Asynchronous Communication Link (ACL) enables one or more Intel microcomputer development systems to communicate with a Digital Equipment Corporation VAX family computer. The link supports Intel Model 800, Intellec Series II, or Intellec Series III development systems. Programmers can use the editing and file management tools of the host computer and then download to the Intel microcomputer development system for debugging and execution. For example, the ACL provides host-to-debug workstation communication for the Intel 432 Cross Development System. Programmers can use their microcomputer development system as a host terminal and control the host directly without changing terminals.



Typical Uses of Asynchronous Communication Link (ACL)

* VAX and VAX/VMS are trademarks of Digital Equipment Corporation.
† UNIX is a trademark of Bell Laboratories.

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June, 1982
Order Number: 172463-001

FUNCTIONAL DESCRIPTION

The Asynchronous Communication Link (ACL) consists of cooperating programs: one that runs on the host computer, and others that run on each microcomputer development system. The development system programs execute under the ISIS-II operating system and use its file system. They invoke the companion program on the VAX-11/780, which runs under either the VAX/VMS or UNIX operating system.

The link provides three modes of communication: on-line transmission, single-line transmission, and file transfer. In on-line mode, the development system functions as a host terminal, enabling the programmer to develop programs using the host computer's editing, compilation, and file-management tools directly from the development system's console. Later, switching to file transfer mode, text files and object code can be downloaded from the host to the development system for debugging and execution. Alternatively, files can be sent back to the host for editing or storage. In single-line mode, the programmer can send single-line commands to the host computer while remaining in the ISIS-II environment.

The user can select transmission rates over the link from 300 to 9600 baud. The link transmits in encapsulated blocks. The receiver program validates the transmission by checking record-number and checksum information in each block's header. In the event of a transmission error, the receiving program recognizes a bad block and requests the sender to retransmit the correct block. The result is highly reliable data communications.

SOFTWARE PACKAGE

The Asynchronous Communications Link Package contains either a VAX/VMS or UNIX compatible magnetic tape, a single- or double-density diskette compatible with the Intellec development system, and the *Asynchronous Communications Link User's Guide* containing installation, configuration, and operation information.

HARDWARE CONNECTION

The Link sends data over an RS232C cable. The communication line from the host computer connects directly to a development system port.

TELECOMMUNICATIONS USING THE LINK

The ACL is ideal for cross-host program development using a commercial timesharing service. This configuration requires RS232C compatible modems and a telecommunications line. Depending on the anticipated level of usage, wide-area telephone service (WATS), a leased line, or a data communications network may be chosen to keep operating overhead low.

SPECIFICATIONS

Software

Asynchronous Communications Link development system programs

VAX/VMS or UNIX companion program

Media

Single- or double-density ISIS-II compatible diskette

600-ft, 1600 bpi magnetic tape, VAX/VMS or UNIX compatible

Manual

Asynchronous Communications Link User's Guide, Order No. 172174-001

Required Host Configuration

VAX-11/780 running VAX/VMS (Version 2.4) or fourth Berkeley distribution of UNIX 32V

Required Intel Development System Configuration

Model 800, Intellec Series II, or Intellec Series III under ISIS-II

Required Connection

RS232C compatible — cable 3M-3349/25 or equivalent; 25-pin connector 3M-3482-1000 or equivalent

Recommended Modems for Telecommunications

300 baud — Bell* 103 modem; VADIC† 3455 modem or equivalent

1200 baud — Bell 202 modem; VADIC 3451 modem or equivalent

9600 baud — Bell 209A (full duplex, leased line) or equivalent

Note: Since one of the two Model 800 ports uses a current loop interface, Model 800 users need a terminal or modem that is current loop compatible, or a current loop/RS232C converter.

ORDERING INFORMATION

Product Name

Asynchronous Communications Link

Ordering Code‡

CDS 432 50 for VAX/VMS systems
CDS 432 51 for UNIX systems

* Bell is a trademark of American Telephone and Telegraph.
† VADIC is a trademark of Racal-Vadic Inc.
‡ See price book for proper suffixes for options and media selection.

Microprocessor Peripherals

6

8041A/8641A/8741A
UNIVERSAL PERIPHERAL INTERFACE
8-BIT MICROCOMPUTER

- **8-Bit CPU plus ROM, RAM, I/O, Timer and Clock in a Single Package**
- **One 8-Bit Status and Two Data Registers for Asynchronous Slave-to-Master Interface**
- **DMA, Interrupt, or Polled Operation Supported**
- **1024 × 8 ROM/EPROM, 64 × 8 RAM, 8-Bit Timer/Counter, 18 Programmable I/O Pins**
- **Fully Compatible with All Microprocessor Families**
- **Interchangeable ROM and EPROM Versions**
- **3.6 MHz 8741A-8 Available**
- **Expandable I/O**
- **RAM Power-Down Capability**
- **Over 90 Instructions: 70% Single Byte**
- **Available in EXPRESS**
  —Standard Temperature Range
  —Extended Temperature Range

The Intel® 8041A/8741A is a general purpose, programmable interface device designed for use with a variety of 8-bit microprocessor systems. It contains a low cost microcomputer with program memory, data memory, 8-bit CPU, I/O ports, timer/counter, and clock in a single 40-pin package. Interface registers are included to enable the UPI device to function as a peripheral controller in MCS-48™, MCS-80™, MCS-85™, MCS-86™, and other 8-bit systems.

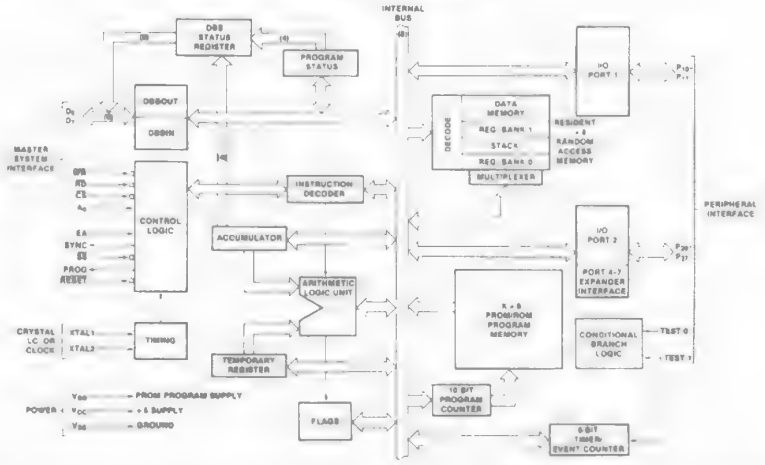
The UPI-41A™ has 1K words of program memory and 64 words of data memory on-chip. To allow full user flexibility the program memory is available as ROM in the 8041A version or as UV-erasable EPROM in the 8741A version. The 8741A and the 8041A are fully pin compatible for easy transition from prototype to production level designs. The 8641A is a one-time programmable (at the factory) 8741A which can be ordered as the first 25 pieces of a new 8041A order. The substitution of 8641A's for 8041A's allows for very fast turnaround for initial code verification and evaluation results.

The device has two 8-bit, TTL compatible I/O ports and two test inputs. Individual port lines can function as either inputs or outputs under software control. I/O can be expanded with the 8243 device which is directly compatible and has 16 I/O lines. An 8-bit programmable timer/counter is included in the UPI device for generating timing sequences or counting external inputs. Additional UPI features include: single 5V supply, low power standby mode (in the 8041A), single-step mode for debug (in the 8741A), and dual working register banks.

Because it's a complete microcomputer, the UPI provides more flexibility for the designer than conventional LSI interface devices. It is designed to be an efficient controller as well as an arithmetic processor. Applications include keyboard scanning, printer control, display multiplexing and similar functions which involve interfacing peripheral devices to microprocessor systems.

PIN CONFIGURATION

BLOCK DIAGRAM



Intel Corporation Assumes No Responsibility for the Use of Any Circuitry Other Than Circuitry Embodied in an Intel Product. No Other Circuit Patent Licenses are Implied.
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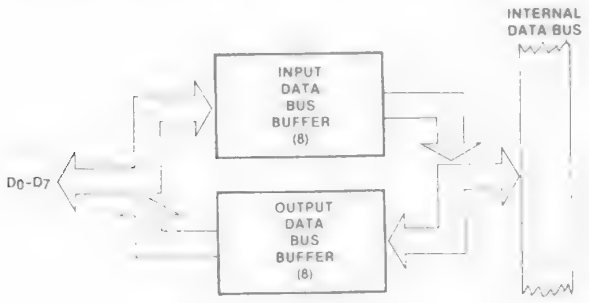
Table 1. Pin Description

Signal	Description
D_0–D_7 (BUS)	Three-state, bidirectional DATA BUS BUFFER lines used to interface the UPI-41A to an 8-bit master system data bus.
P_{10}–P_{17}	8-bit, PORT 1 quasi-bidirectional I/O lines.
P_{20}–P_{27}	8-bit, PORT 2 quasi-bidirectional I/O lines. The lower 4 bits (P_{20}–P_{23}) interface directly to the 8243 I/O expander device and contain address and data information during PORT 4–7 access. The upper 4 bits (P_{24}–P_{27}) can be programmed to provide Interrupt Request and DMA Handshake capability. Software control can configure P_{24} as OBF (Output Buffer Full), P_{25} as $\overline{IBF}$ (Input Buffer Full), P_{26} as DRQ (DMA Request), and P_{27} as $\overline{DACK}$ (DMA ACKnowledge).
$\overline{WR}$	I/O write input which enables the master CPU to write data and command words to the UPI-41A INPUT DATA BUS BUFFER.
$\overline{RD}$	I/O read input which enables the master CPU to read data and status words from the OUTPUT DATA BUS BUFFER or status register.
$\overline{CS}$	Chip select input used to select one UPI-41A out of several connected to a common data bus.
A_0	Address input used by the master processor to indicate whether byte transfer is data or command. During a write operation flag F_1 is set to the status of the A_0 input.
TEST 0, TEST 1	Input pins which can be directly tested using conditional branch instructions. T_1 also functions as the event timer input (under software control). T_0 is used during PROM programming and verification in the 8741A.

Signal	Description
XTAL1, XTAL2	Inputs for a crystal, LC or an external timing signal to determine the internal oscillator frequency.
SYNC	Output signal which occurs once per UPI-41A instruction cycle. SYNC can be used as a strobe for external circuitry; it is also used to synchronize single step operation.
EA	External access input which allows emulation, testing and PROM/ROM verification.
PROG	Multifunction pin used as the program pulse input during PROM programming. During I/O expander access the PROG pin acts as an address/data strobe to the 8243.
$\overline{RESET}$	Input used to reset status flip-flops and to set the program counter to zero. $\overline{RESET}$ is also used during PROM programming and verification. $\overline{RESET}$ should be held low for a minimum of 8 instruction cycles after power-up.
$\overline{SS}$	Single step input used in the 8741A in conjunction with the SYNC output to step the program through each instruction.
V_{CC}	+5V main power supply pin.
V_{DD}	+5V during normal operation. +25V during programming operation. Low power standby pin in ROM version.
V_{SS}	Circuit ground potential.

UPI-41A™ FEATURES AND ENHANCEMENTS

1. Two Data Bus Buffers, one for input and one for output. This allows a much cleaner Master/Slave protocol.



2. 8 Bits of Status

ST_7	ST_6	ST_5	ST_4	F_1	F_0	IBF	OBF
D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0

ST_4-ST_7 are user definable status bits. These bits are defined by the "MOV STS, A" single byte, single cycle instruction. Bits 4-7 of the accumulator are moved to bits 4-7 of the status register. Bits 0-3 of the status register are not affected.

MOV STS, A Op Code: 90H

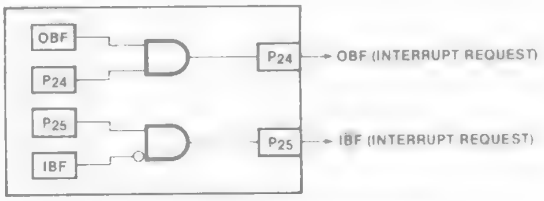
1	0	0	1	0	0	0	0
D_7							D_0

3. $\overline{RD}$ and $\overline{WR}$ are edge triggered. IBF, OBF, F_1 and INT change internally after the trailing edge of $\overline{RD}$ or $\overline{WR}$.

4. P_{24} and P_{25} are port pins or Buffer Flag pins which can be used to interrupt a master processor. These pins default to port pins on Reset.

   If the "EN FLAGS" instruction has been executed, P_{24} becomes the OBF (Output Buffer Full) pin. A "1" written to P_{24} enables the OBF pin (the pin outputs the OBF Status Bit). A "0" written to P_{24} disables the OBF pin (the pin remains low). This pin can be used to indicate that valid data is available from the UPI-41A (in Output Data Bus Buffer).

   If "EN FLAGS" has been executed, P_{25} becomes the $\overline{IBF}$ (Input Buffer Full) pin. A "1" written to P_{25} enables the $\overline{IBF}$ pin (the pin outputs the inverse of the IBF Status Bit). A "0" written to P_{25} disables the $\overline{IBF}$ pin (the pin remains low). This pin can be used to indicate that the UPI-41A is ready for data.



DATA BUS BUFFER INTERRUPT CAPABILITY

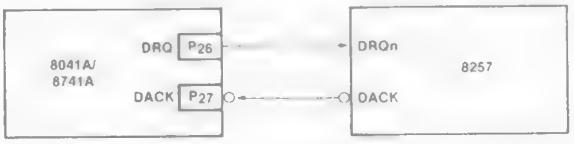
EN FLAGS Op Code: 0F5H

1	1	1	1	0	1	0	1
D_7							D_0

5. P_{26} and P_{27} are port pins or DMA handshake pins for use with a DMA controller. These pins default to port pins on Reset.

   If the "EN DMA" instruction has been executed, P_{26} becomes the DRQ (DMA ReQuest) pin. A "1" written to P_{26} causes a DMA request (DRQ is activated). DRQ is deactivated by DACK·RD, DACK·WR, or execution of the "EN DMA" instruction.

   If "EN DMA" has been executed, P_{27} becomes the $\overline{DACK}$ (DMA ACKnowledge) pin. This pin acts as a chip select input for the Data Bus Buffer registers during DMA transfers.



DMA HANDSHAKE CAPABILITY

EN DMA Op Code: 0E5H

1	1	1	0	0	1	0	1
D_1							D_0

APPLICATIONS

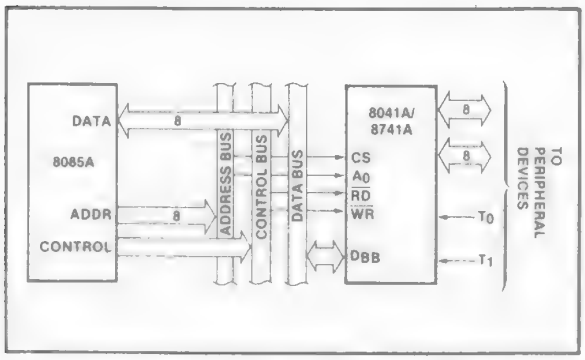


Figure 1. 8085A-8041A Interface

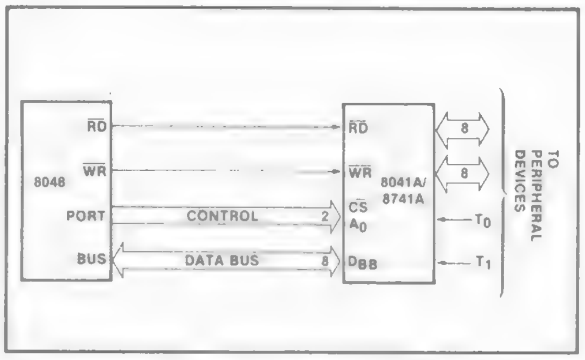


Figure 2. 8048-8041A Interface

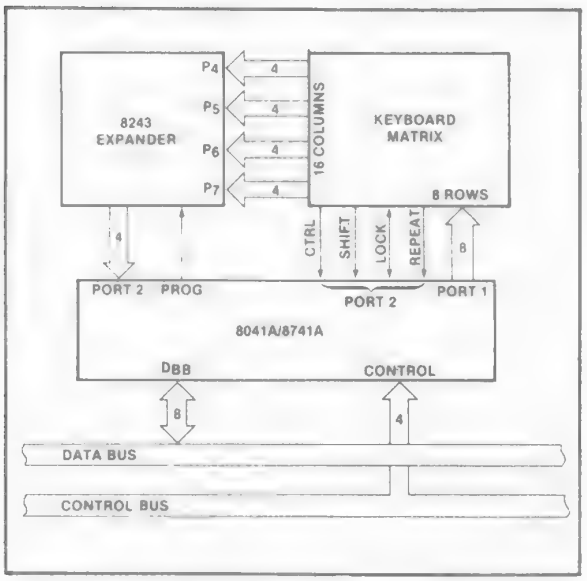


Figure 3. 8041A-8243 Keyboad Scanner

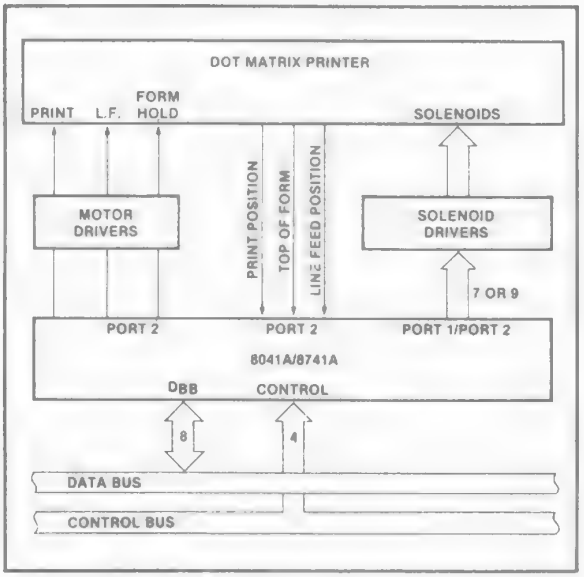


Figure 4. 8041A Matrix Printer Interface

PROGRAMMING, VERIFYING, AND ERASING THE 8741A EPROM

Programming Verification

In brief, the programming process consists of: activating the program mode, applying an address, latching the address, applying data, and applying a programming pulse. Each word is programmed completely before moving on to the next and is followed by a verification step. The following is a list of the pins used for programming and a description of their functions:

Pin	Function
XTAL 1	Clock Input (1 to 6MHz)
$\overline{\text{Reset}}$	Initialization and Address Latching
Test 0	Selection of Program or Verify Mode
EA	Activation of Program/Verify Modes
BUS	Address and Data Input Data Output During Verify
P20-1	Address Input
V_{DD}	Programming Power Supply
PROG	Program Pulse Input

WARNING:

An attempt to program a missocketed 8741A will result in severe damage to the part. An indication of a properly socketed part is the appearance of the SYNC clock output. The lack of this clock may be used to disable the programmer.

The Program/Verify sequence is:

1. A_0 = 0V, $\overline{CS}$ = 5V, EA = 5V, $\overline{RESET}$ = 0V, TEST0 = 5V, V_{DD} = 5V, clock applied or internal oscillator operating, BUS and PROG floating.
2. Insert 8741A in programming socket
3. TEST 0 = 0v (select program mode)
4. EA = 23V (activate program mode)
5. Address applied to BUS and P20-1
6. $\overline{RESET}$ = 5v (latch address)
7. Data applied to BUS
8. V_{DD} = 25v (programming power)
9. PROG = 0v followed by one 50ms pulse to 23V
10. V_{DD} = 5v
11. TEST 0 = 5v (verify mode)
12. Read and verify data on BUS
13. TEST 0 = 0v
14. $\overline{RESET}$ = 0v and repeat from step 5
15. Programmer should be at conditions of step 1 when 8741A is removed from socket.

8741A Erasure Characteristics

The erasure characteristics of the 8741A are such that erasure begins to occur when exposed to light with wavelengths shorter than approximately 4000 Angstroms (Å). It should be noted that sunlight and certain types of fluorescent lamps have wavelengths in the 3000-4000Å range. Data show that constant exposure to room level fluorescent lighting could erase the typical 8741A in approximately 3 years while it would take approximately one week to cause erasure when exposed to direct sunlight. If the 8741A is to be exposed to these types of lighting conditions for extended periods of time, opaque labels are available from Intel which should be placed over the 8741A window to prevent unintentional erasure.

The recommended erasure procedure for the 8741A is exposure to shortwave ultraviolet light which has a wavelength of 2537Å. The integrated dose (i.e., UV intensity × exposure time) for erasure should be a minimum of 15 w-sec/cm^2. The erasure time with this dosage is approximately 15 to 20 minutes using an ultraviolet lamp with a 12,000 μW/cm^2 power rating. The 8741A should be placed within one inch of the lamp tubes during erasure. Some lamps have a filter on their tubes which should be removed before erasure.

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias . . . . . 0°C to 70°C
Storage Temperature . . . . . – 65°C to + 150°C
Voltage on Any Pin With Respect
to Ground . . . . . 0.5V to + 7V
Power Dissipation . . . . . 1.5 Watt

*COMMENT: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. AND OPERATING CHARACTERISTICS

T_A=0°C to 70°C, V_{SS}=0V, V_{CC}=V_{DD}=+5V ±10%*

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_{IL}	Input Low Voltage (Except XTAL1, XTAL2, $\overline{RESET}$)	– 0.5	0.8	V	
V_{IL1}	Input Low Voltage (XTAL1, XTAL2, $\overline{RESET}$)	– 0.5	0.6	V	
V_{IH}	Input High Voltage (Except XTAL1, XTAL2, $\overline{RESET}$)	2.2	V_{CC}		
V_{IH1}	Input High Voltage (XTAL1, XTAL2, $\overline{RESET}$)	3.8	V_{CC}	V	
V_{OL}	Output Low Voltage (D_0-D_7)		0.45	V	I_{OL} = 2.0 mA
V_{OL1}	Output Low Voltage ($P_{10}P_{17}$, $P_{20}P_{27}$, Sync)		0.45	V	I_{OL} = 1.6 mA
V_{OL2}	Output Low Voltage (Prog)		0.45	V	I_{OL} = 1.0 mA
V_{OH}	Output High Voltage (D_0-D_7)	2.4		V	I_{OH} = – 400 μA
V_{OH1}	Output High Voltage (All Other Outputs)	2.4		V	I_{OH} = – 50 μA
I_{IL}	Input Leakage Current (T_0, T_1, $\overline{RD}$, $\overline{WR}$, $\overline{CS}$, A_0, EA)		± 10	μA	$V_{SS} \le V_{IN} \le V_{CC}$
I_{OZ}	Output Leakage Current (D_0-D_7, High Z State)		± 10	μA	V_{SS}+0.45 $\le V_{IN} \le V_{CC}$
I_{L1}	Low Input Load Current ($P_{10}P_{17}$, $P_{20}P_{27}$)		0.5	mA	V_{IL} = 0.8V
I_{L11}	Low Input Load Current ($\overline{RESET}$, $\overline{SS}$)		0.2	mA	V_{IL} = 0.8V
I_{DD}	V_{DD} Supply Current		15	mA	Typical = 5 mA
I_{CC}+I_{DD}	Total Supply Current		125	mA	Typical = 60 mA

A.C. CHARACTERISTICS

T_A=0°C to 70°C, V_{SS}=0V, V_{CC}=V_{DD}=+5V ±10%*

DBB READ

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AR}	$\overline{CS}$, A_0 Setup to $\overline{RD}$↓	0		ns	
t_{RA}	$\overline{CS}$, A_0 Hold After $\overline{RD}$↑	0		ns	
t_{RR}	$\overline{RD}$ Pulse Width	250		ns	
t_{AD}	$\overline{CS}$, A_0 to Data Out Delay		225	ns	C_L = 150 pF
t_{RD}	$\overline{RD}$↓ to Data Out Delay		225	ns	C_L = 150 pF
t_{DF}	$\overline{RD}$↑ to Data Float Delay		100	ns	
t_{CY}	Cycle Time (Except 8741A-8)	2.5	15	μs	6.0 MHz XTAL
t_{CY}	Cycle Time (8741A-8)	4.17	15	μs	3.6 MHz XTAL

DBB WRITE

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AW}	$\overline{CS}$, A_0 Setup to $\overline{WR}$↓	0		ns	
t_{WA}	$\overline{CS}$, A_0 Hold After $\overline{WR}$↑	0		ns	
t_{WW}	$\overline{WR}$ Pulse Width	250		ns	
t_{DW}	Data Setup to $\overline{WR}$↑	150		ns	
t_{WD}	Data Hold After $\overline{WR}$↑	0		ns	

A.C. TIMING SPECIFICATION FOR PROGRAMMING

T_A=0°C to 70°C, V_{CC}=+5V ±10% *

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AW}	Address Setup Time to $\overline{RESET}$ ↑	4tCY			
t_{WA}	Address Hold Time After $\overline{RESET}$ ↑	4tCY			
t_{DW}	Data in Setup Time to PROG ↑	4tCY			
t_{WD}	Data in Hold Time After PROG ↓	4tCY			
t_{PH}	$\overline{RESET}$ Hold Time to Verify	4tCY			
t_{VDDW}	V_{DD} Setup Time to PROG ↑	4tCY			
t_{VDDH}	V_{DD} Hold Time After PROG ↓	0			
t_{PW}	Program Pulse Width	50	60	mS	
t_{TW}	Test 0 Setup Time for Program Mode	4tCY			
t_{WT}	Test 0 Hold Time After Program Mode	4tCY			
t_{DO}	Test 0 to Data Out Delay		4tCY		
t_{WW}	$\overline{RESET}$ Pulse Width to Latch Address	4tCY			
t_r, t_f	V_{DD} and PROG Rise and Fall Times	0.5	2.0	μS	
t_{CY}	CPU Operation Cycle Time	5.0		μS	
t_{RE}	$\overline{RESET}$ Setup Time Before EA ↑.	4tCY			

Note: If TEST 0 is high, t_{DO} can be triggered by $\overline{RESET}$ ↑.

* For Extended Temperature EXPRESS, use M8741A electrical parameters.

D.C. SPECIFICATION FOR PROGRAMMING

T_A = 25°C ±5°C, V_{CC} = 5V ±5%, V_{DD} = 25V ±1V

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_{DOH}	V_{DD} Program Voltage High Level	24.0	26.0	V	
V_{DDL}	V_{DD} Voltage Low Level	4.75	5.25	V	
V_{PH}	PROG Program Voltage High Level	21.5	24.5	V	
V_{PL}	PROG Voltage Low Level		0.2	V	
V_{EAH}	EA Program or Verify Voltage High Level	21.5	24.5	V	
V_{EAL}	EA Voltage Low Level		5.25	V	
I_{DD}	V_{DD} High Voltage Supply Current		30.0	mA	
I_{PROG}	PROG High Voltage Supply Current		16.0	mA	
I_{EA}	EA High Voltage Supply Current		1.0	mA	

A.C. CHARACTERISTICS—PORT 2

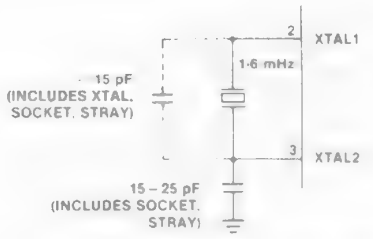
T_A=0°C to 70°C, : V_{CC}= +5V ±10%

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{CP}	Port Control Setup Before Falling Edge of PROG	110		ns	
t_{PC}	Port Control Hold After Falling Edge of PROG	100		ns	
t_{PR}	PROG to Time P2 Input Must Be Valid		810	ns	
t_{PF}	Input Data Hold Time	0	150	ns	
t_{DP}	Output Data Setup Time	250		ns	
t_{PD}	Output Data Hold Time	65		ns	
t_{PP}	PROG Pulse Width	1200		ns	

A.C. CHARACTERISTICS—DMA

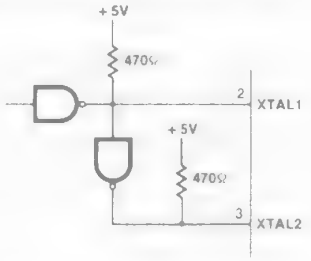
Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{ACC}	$\overline{DACK}$ to $\overline{WR}$ or $\overline{RD}$	0		ns	
t_{CAC}	$\overline{RD}$ or $\overline{WR}$ to $\overline{DACK}$	0		ns	
t_{ACD}	$\overline{DACK}$ to Data Valid		225	ns	$C_L = 150$ pF
t_{CRQ}	$\overline{RD}$ or $\overline{WR}$ to DRQ Cleared		200	ns	

CRYSTAL OSCILLATOR MODE



CRYSTAL SERIES RESISTANCE SHOULD BE <75Ω AT 6 MHz; <180Ω AT 3.6 MHz

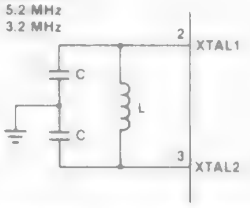
DRIVING FROM EXTERNAL SOURCE



BOTH XTAL1 AND XTAL2 SHOULD BE DRIVEN. RESISTORS TO V_{CC} ARE NEEDED TO ENSURE $V_{IH} = 3.8V$ IF TTL CIRCUITRY IS USED

LC OSCILLATOR MODE

L	C	NOMINAL f
45 μH	20 pF	5.2 MHz
120 μH	20 pF	3.2 MHz



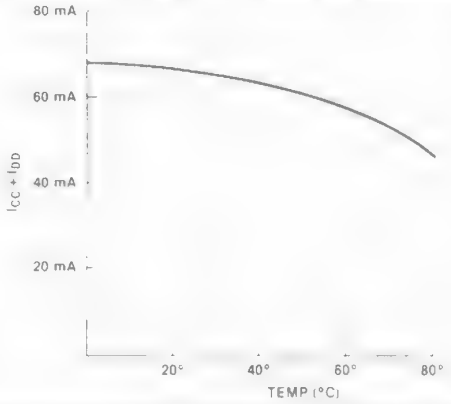
$f = \frac{1}{2\pi\sqrt{LC'}}$

$C' = \frac{C + 3C_{PP}}{2}$

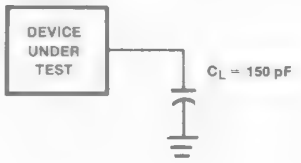
$C_{PP} \approx 5 - 10$ pF PIN-TO-PIN CAPACITANCE

EACH C SHOULD BE APPROXIMATELY 20 pF, INCLUDING STRAY CAPACITANCE.

TYPICAL 8041/8741A CURRENT



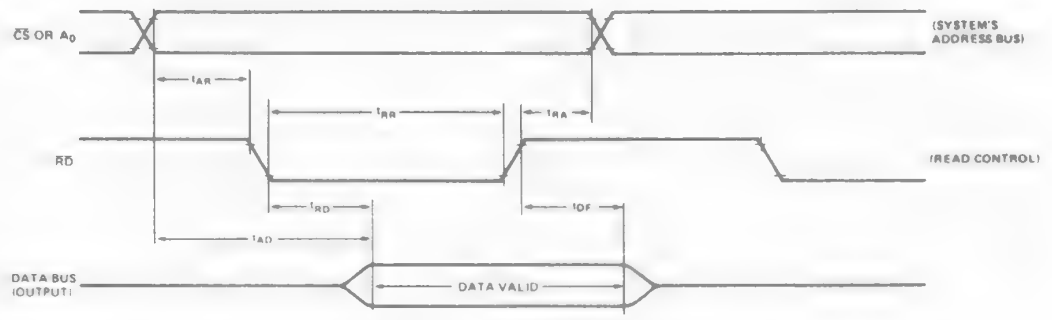
A.C. TESTING LOAD CIRCUIT



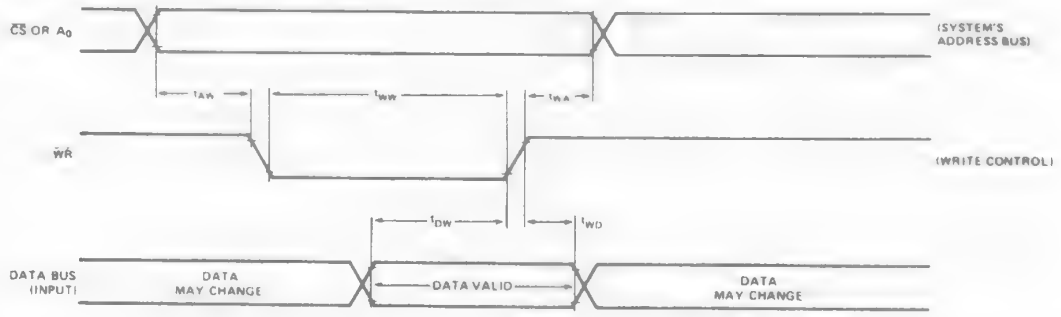
AFN-00188B

WAVEFORMS

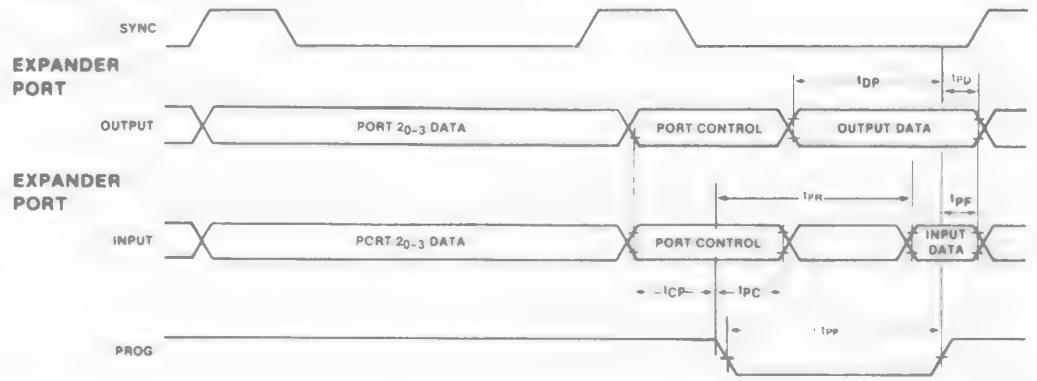
READ OPERATION—DATA BUS BUFFER REGISTER.



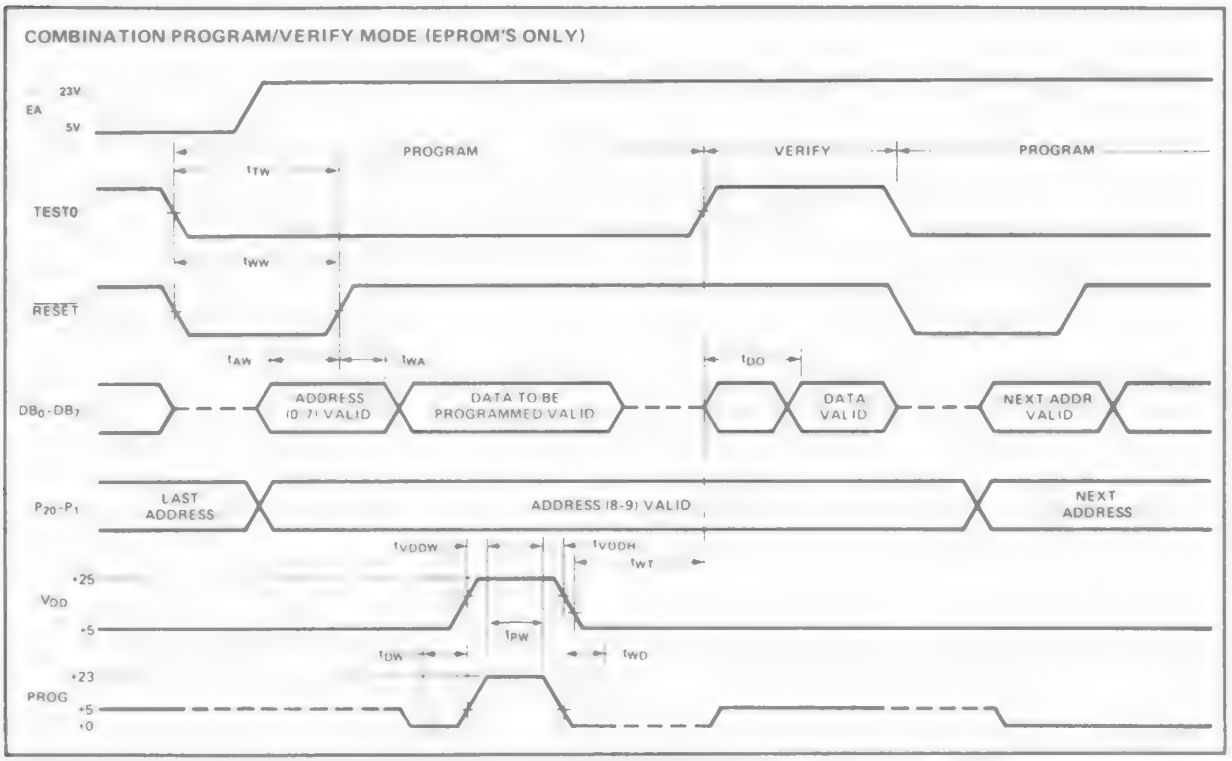
WRITE OPERATION—DATA BUS BUFFER REGISTER.

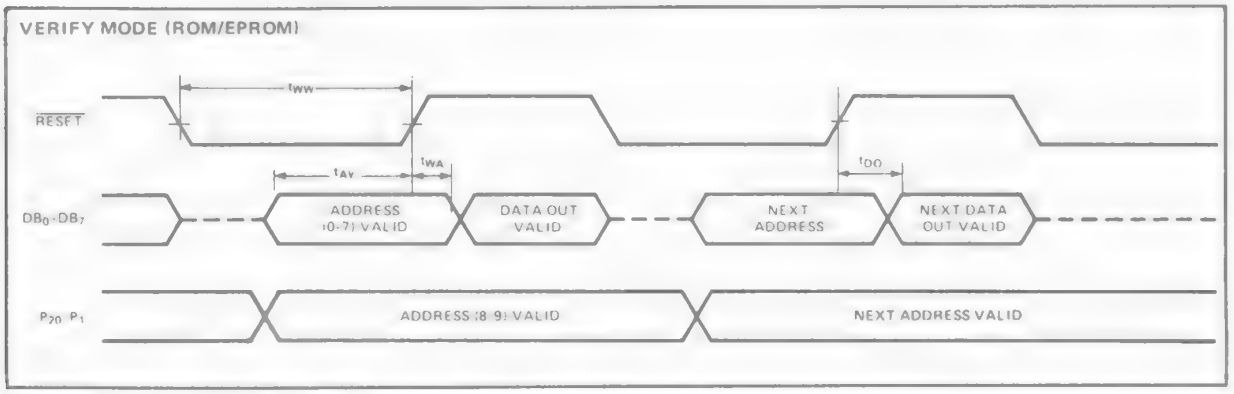


PORT 2 TIMING



WAVEFORMS FOR PROGRAMMING



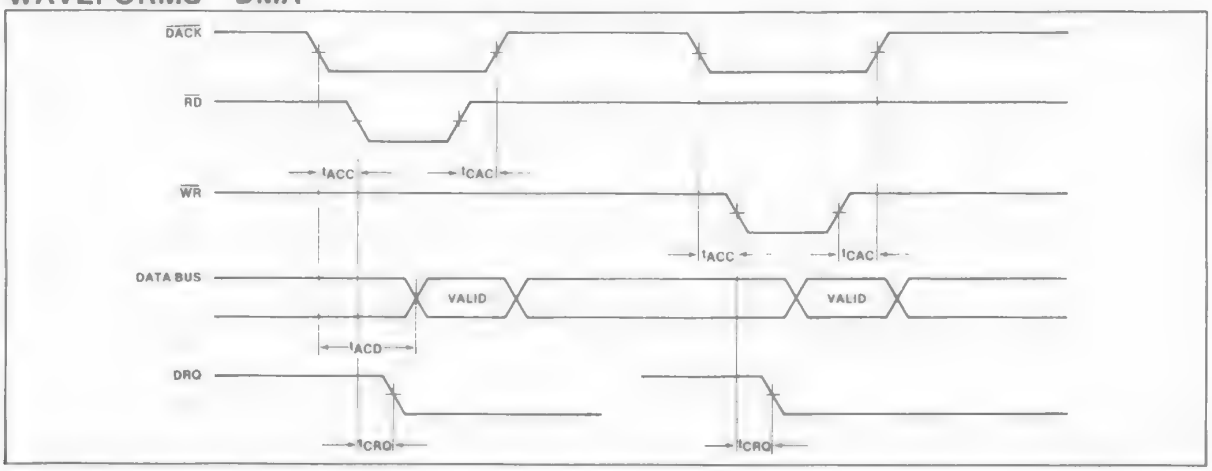


NOTES:
1. PROG MUST FLOAT IF EA IS LOW (i.e., ≠23V), OR IF T0 = 5V FOR THE 8741A. FOR THE 8041A PROG MUST ALWAYS FLOAT.
2. XTAL1 AND XTAL 2 DRIVEN BY 3.6 MHz CLOCK WILL GIVE 4.17 μsec t_{CY}. THIS IS ACCEPTABLE FOR 8741A-8 PARTS AS WELL AS STANDARD PARTS.
3. A0 MUST BE HELD LOW (i.e., = 0V) DURING PROGRAM/VERIFY MODES.

The 8741A EPROM can be programmed by either of two Intel products:

1. PROMPT-48 Microcomputer Design Aid, or
2. Universal PROM Programmer (UPP series) peripheral of the Intellec® Development System with a UPP-848 Personality Card.

WAVEFORMS—DMA



INPUT AND OUTPUT WAVEFORMS FOR A.C. TESTS

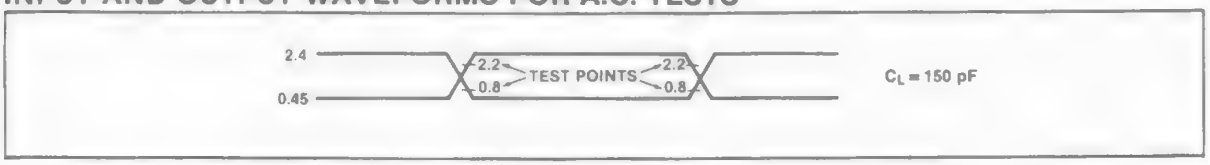


Table 2. UPI™ Instruction Set

Mnemonic	Description	Bytes	Cycles
Accumulator			
ADD A,Rr	Add register to A	1	1
ADD A,@Rr	Add data memory to A	1	1
ADD A,#data	Add immediate to A	2	2
ADDC A,Rr	Add register to A with carry	1	1
ADDC A,@Rr	Add data memory to A with carry	1	1
ADDC A, #data	Add immed. to A with carry	2	[illegible]
ANL A,Rr	AND register to A	1	1
ANL A,@Rr	AND data memory to A	1	1
ANL A,#data	AND immediate to A	2	2
ORL A,Rr	OR register to A	1	1
ORL A,@Rr	OR data memory to A	1	1
ORL A,#data	OR immediate to A	2	2
XRL A,Rr	Exclusive OR register to A	1	1
XRL A,@Rr	Exclusive OR data memory to A	1	1
XRL A,#data	Exclusive OR immediate to A	2	[illegible]
INC A	Increment A	1	1
DEC A	Decrement A	1	1
CLR A	Clear A	1	1
CPL A	Complement A	1	1
DA A	Decimal Adjust A	1	1
SWAP A	Swap nibbles of A	1	1
RL A	Rotate A left	1	1
RCL A	Rotate A left through carry	1	1
RR A	Rotate A right	1	1
RRC A	Rotate A right through carry	1	1

Table 2. UPI™ Instruction Set (Cont'd.)

Mnemonic	Description	Bytes	Cycles
Input/Output			
In A,Pp	Input port to A	1	2
OUTL Pp,A	Output A to port	1	2
ANL Pp,#data	AND immediate to port	2	2
ORL Pp,#data	OR immediate to port	2	2
In A,DBB	Input DBB to A, clear IBF	1	1
OUT DBB,A	Output A to DBB, set OBF	1	1
MOV STS,A	A_4–A_7 to Bits 4–7 of Status	1	1
MOVD A,Pp	Input Expander port to A	1	2
MOVD Pp,A	Output A to Expander port	1	2
ANLD Pp,A	AND A to Expander	1	2
ORLD Pp,A	OR A to Expander port	1	2
Data Moves			
MOV A,Rr	Move register to A	1	1
MOV A,@Rr	Move data memory to A	1	1
MOV A,#data	Move immediate to A	2	2
MOV Rr,A	Move A to register	1	1
MOV @Rr,A	Move A to data memory	1	1
MOV Rr,#data	Move immediate to register	2	2
MOV @Rr, #data	Move immediate to data memory	2	2
MOV A,PSW	Move PSW to A	1	1
MOV PSW,A	Move A to PSW	1	1
XCH A,Rr	Exchange A and register	1	1
XCH A,@Rr	Exchange A and data memory	1	1
XCHD A,@Rr	Exchange digit of A and register	1	1
MOVP A,@A	Move to A from current page	1	2
MOVP3, A,@A	Move to A from page 3	1	2
Timer/Counter			
MOV A,T	Read Timer/Counter	1	1
MOV T,A	Load Timer/Counter	1	1
STRT T	Start Timer	1	1
STRT CNT	Start Counter	1	1
STOP TCNT	Stop Timer/Counter	1	1
EN TCNTI	Enable Timer/Counter	1	1
DIS TCNTI	Disable Timer/ Counter Interrupt	1	1

Mnemonic	Description	Bytes	Cycles
Control			
EN DMA	Enable DMA Hand-shake Lines	1	1
EN I	Enable IBF Interrupt	1	1
DIS I	Disable IBF Interrupt	1	1
EN FLAGS	Enable Master Interrupts	1	1
SEL RB0	Select register bank 0	1	1
SEL RB1	Select register bank 1	1	1
NOP	No Operation	1	1
Registers			
INC Rr	Increment register	1	1
INC @Rr	Increment data memory	1	1
DEC Rr	Decrement register	1	1
Subroutine			
CALL addr	Jump to subroutine	2	2
RET	Return	1	2
RETR	Return and restore status	1	2
Flags			
CLR C	Clear Carry	1	1
CPL C	Complement Carry	1	1
CLR F0	Clear Flag 0	1	1
CPL F0	Complement Flag 0	1	1
CLR F1	Clear F1 Flag	1	1
CPL F1	Complement F1 Flag	1	1
Branch			
JMP addr	Jump unconditional	2	2
JMPP @A	Jump indirect	1	2
DJNZ Rr,addr	Decrement register and jump	2	2
JC addr	Jump on Carry=1	2	2
JNC addr	Jump on Carry=0	2	2
JZ addr	Jump on A Zero	2	2
JNZ addr	Jump on A not Zero	2	2
JT0 addr	Jump on T0=1	2	2
JNT0 addr	Jump on T0=0	2	2
JT1 addr	Jump on T1=1	2	2
JNT1 addr	Jump on T1=0	2	2
JF0 addr	Jump on F0 Flag=1	2	2
JF1 addr	Jump on F1 Flag=1	2	2
JTF addr	Jump on Timer Flag=1, Clear Flag	2	2
JN1BF addr	Jump on IBF Flag=0	2	2
JOBF addr	Jump on OBF Flag=1	2	2
JBb addr	Jump on Accumulator Bit	2	2

PRELIMINARY

8042/8742
UNIVERSAL PERIPHERAL INTERFACE 8-BIT MICROCOMPUTER

- **8042/8742: 12 MHz**
- **Pin, Software and Architecturally Compatible with 8041A/8741A**
- **8-Bit CPU plus ROM, RAM, I/O, Timer and Clock in a Single Package**
- **2048 × 8 ROM/EPROM, 128 × 8 RAM, 8-Bit Timer/Counter, 18 Programmable I/O Pins**
- **One 8-Bit Status and Two Data Registers for Asynchronous Slave-to-Master Interface**
- **DMA, Interrupt, or Polled Operation Supported**
- **Fully Compatible with all Intel and Most Other Microprocessor Families**
- **Interchangeable ROM and EPROM Versions**
- **Expandable I/O**
- **RAM Power-Down Capability**
- **Over 90 Instructions: 70% Single Byte**
- **Available in EXPRESS —Standard Temperature Range**

The Intel 8042/8742 is a general-purpose Universal Peripheral Interface that allows the designer to grow his own customized solution for peripheral device control. It contains a low-cost microcomputer with 2K of program memory, 128 bytes of data memory, 8-bit CPU, I/O ports, 8-bit timer/counter, and clock generator in a single 40-pin package. Interface registers are included to enable the UPI device to function as a peripheral controller in the MCS-48™, MCS-51™, MCS-80™, MCS-85™, iAPX-88, iAPX-86 and other 8-, 16-bit systems.

The 8042/8742 is software, pin, and architecturally compatible with the 8041A, 8741A. The 8042/8742 doubles the on-chip memory space to allow for additional features and performance to be incorporated in upgraded 8041A/8741A designs. For new designs, the additional memory and performance of the 8042/8742 extends the UPI concept to more complex motor control tasks, 80-column printers and process control applications as examples.

To allow full user flexibility, the program memory is available as ROM in the 8042 version or as UV-erasable EPROM in the 8742 version. The 8742 and the 8042 are fully pin compatible for easy transition from prototype to production level designs. The 8642 is a one-time programmable (at the factory) 8742 which can be ordered as the first 25 pieces of a new 8042 order. The substitution of 8642's for 8042's allows for very fast turnaround for initial code verification and evaluation results.

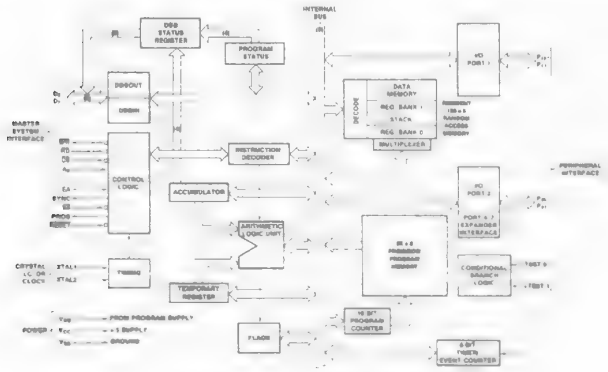


Figure 1. Block Diagram

Figure 2. Pin Configuration

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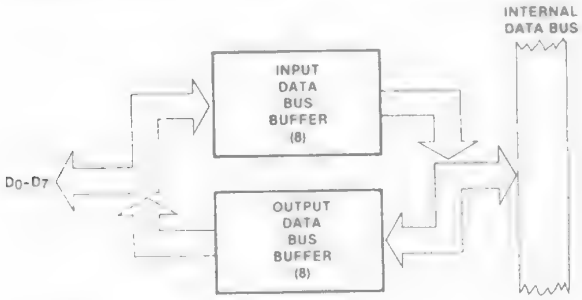
Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
TEST 0, TEST 1	1 39	I	**Test Inputs:** Input pins which can be directly tested using conditional branch instructions. **Frequency Reference:** TEST 1 (T_1) also functions as the event timer input (under software control). TEST 0 (T_0) is used during PROM programming and verification in the 8742.
XTAL 1, XTAL 2	2 3	I	**Inputs:** Inputs for a crystal, LC or an external timing signal to determine the internal oscillator frequency.
$\overline{RESET}$	4	I	**Reset:** Input used to reset status flip-flops and to set the program counter to zero. $\overline{RESET}$ is also used during PROM programming and verification.
$\overline{SS}$	5	I	**Single Step:** Single step input used in conjunction with the SYNC output to step the program through each instruction. (8742 only)
$\overline{CS}$	6	I	**Chip Select:** Chip select input used to select one UPI microcomputer out of several connected to a common data bus.
EA	7	I	**External Access:** External access input which allows emulation, testing and PROM/ROM verification. This pin should be tied low if unused.
$\overline{RD}$	8	I	**Read:** I/O read input which enables the master CPU to read data and status words from the OUTPUT DATA BUS BUFFER or status register.
A_0	9	I	**Command/Data Select:** Address input used by the master processor to indicate whether byte transfer is data ($A_0=0$, F1 is reset) or command ($A_0=1$, F1 is set).
$\overline{WR}$	10	I	**Write:** I/O write input which enables the master CPU to write data and command words to the UPI INPUT DATA BUS BUFFER.
SYNC	11	O	**Output Clock:** Output signal which occurs once per UPI-42 instruction cycle. SYNC can be used as a strobe for external circuitry; it is also used to synchronize single step operation.
D_0-D_7 (BUS)	12-19	I/O	**Data Bus:** Three-state, bidirectional DATA BUS BUFFER lines used to interface the UPI-42 microcomputer to an 8-bit master system data bus.
P_{10}-P_{17}	27-34	I/O	**Port 1:** 8-bit, PORT 1 quasi-bidirectional I/O lines.
P_{20}-P_{27}	21-24 35-38	I/O	**Port 2:** 8-bit, PORT 2 quasi-bidirectional I/O lines. The lower 4 bits (P_{20}-P_{23}) interface directly to the 8243 I/O expander device and contain address and data information during PORT 4-7 access. The upper 4 bits (P_{24}-P_{27}) can be programmed to provide interrupt Request and DMA Handshake capability. Software control can configure P_{24} as Output Buffer Full (OBF) interrupt, P_{25} as Input Buffer Full ($\overline{IBF}$) interrupt, P_{26} as DMA Request ($\overline{DRQ}$), and P_{27} as DMA ACKnowledge ($\overline{DACK}$).
PROG	25	I/O	**Program:** Multifunction pin used as the program pulse input during PROM programming. During I/O expander access the PROG pin acts as an address/data strobe to the 8243. This pin should be tied high if unused.
V_{CC}	40		**Power:** +5V main power supply pin.
V_{DD}	26		**Power:** +5V during normal operation. +21V during programming operation. Low power standby pin in ROM version.
V_{SS}	20		**Ground:** Circuit ground potential.

UPI-42 FEATURES

1. Two Data Bus Buffers, one for input and one for output. This allows a much cleaner Master/Slave protocol.



2. 8 Bits of Status

ST_7	ST_6	ST_5	ST_4	F_1	F_0	IBF	OBF
D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0

ST_4–ST_7 are user definable status bits. These bits are defined by the "MOV STS, A" single byte, single cycle instruction. Bits 4-7 of the accumulator are moved to bits 4-7 of the status register. Bits 0-3 of the status register are not affected.

MOV STS, A Op Code: 90H

1	0	0	1	0	0	0	0
D_7							D_0

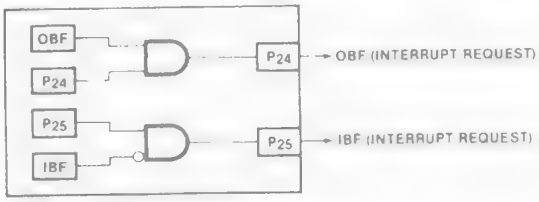
3. $\overline{RD}$ and $\overline{WR}$ are edge triggered. IBF, OBF, F_1 and INT change internally after the trailing edge of $\overline{RD}$ or $\overline{WR}$.

During the time that the host CPU is reading the status register, the 8042/8742 is prevented from updating this register or is 'locked out.'

4. P_{24} and P_{25} are port pins or Buffer Flag pins which can be used to interrupt a master processor. These pins default to port pins on Reset.

   If the "EN FLAGS" instruction has been executed, P_{24} becomes the OBF (Output Buffer Full) pin. A "1" written to P_{24} enables the OBF pin (the pin outputs the OBF Status Bit). A "0" written to P_{24} disables the OBF pin (the pin remains low). This pin can be used to indicate that valid data is available from the UPI-41A (in Output Data Bus Buffer).

   If "EN FLAGS" has been executed, P_{25} becomes the $\overline{IBF}$ (Input Buffer Full) pin. A "1" written to P_{25} enables the $\overline{IBF}$ pin (the pin outputs the inverse of the IBF Status Bit). A "0" written to P_{25} disables the $\overline{IBF}$ pin (the pin remains low). This pin can be used to indicate that the UPI-42 is ready for data.



DATA BUS BUFFER INTERRUPT CAPABILITY

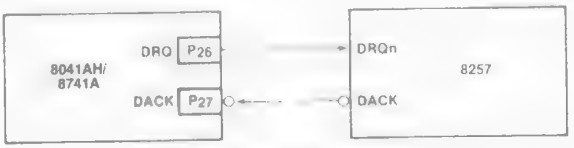
EN FLAGS Op Code: 0F5H

1	1	1	1	0	1	0	1
D_7							D_0

5. P_{26} and P_{27} are port pins or DMA handshake pins for use with a DMA controller. These pins default to port pins on Reset.

   If the "EN DMA" instruction has been executed, P_{26} becomes the DRQ (DMA ReQuest) pin. A "1" written to P_{26} causes a DMA request (DRQ is activated). DRQ is deactivated by DACK·RD, DACK·WR, or execution of the "EN DMA" instruction.

   If "EN DMA" has been executed, P_{27} becomes the $\overline{DACK}$ (DMA ACKnowledge) pin. This pin acts as a chip select input for the Data Bus Buffer registers during DMA transfers.



DMA HANDSHAKE CAPABILITY

EN DMA Op Code: 0E5H

1	1	1	0	0	1	0	1
D_1							D_0

6. The RESET input on the 8042/8742 includes a 2-stage synchronizer to support reliable reset operation for 12 MHz operation.

7. When EA is enabled on the 8042/8742, the program counter is placed on Port 1 and the lower three bits of Port 2 (MSB = P_{22}, LSB = P_{10}). On the 8042/8742 this information is multiplexed with PORT DATA (see port timing diagrams at end of this data sheet).

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APPLICATIONS

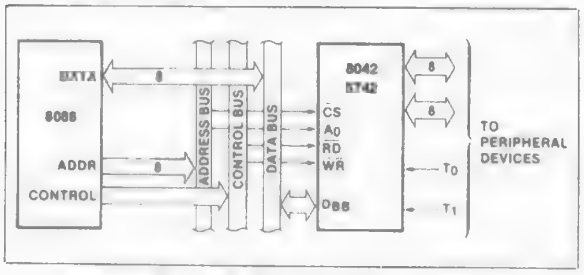

Figure 3. 8088-8042/8742 Interface

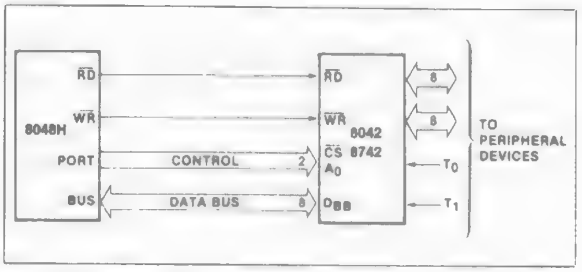

Figure 4. 8048H-8042/8742 Interface

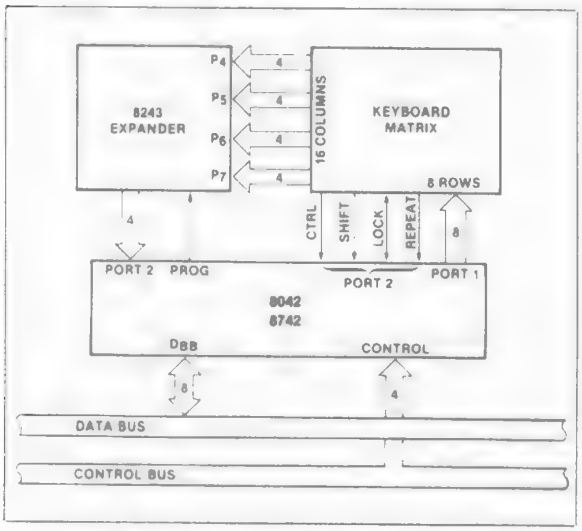

Figure 5. 8042/8742-8243 Keyboard Scanner

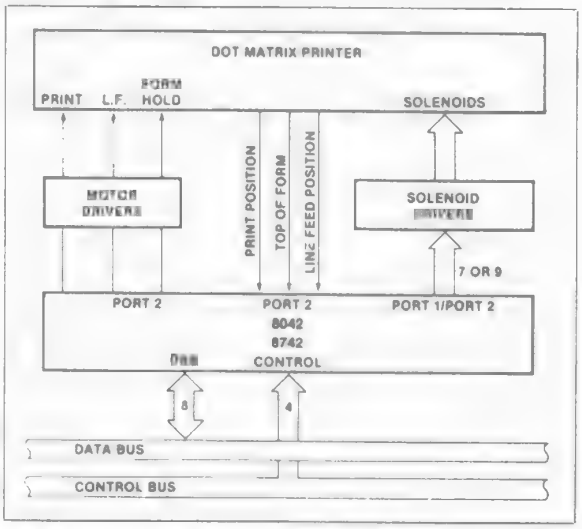

Figure 6. 8042/8742 80-Column Matrix Printer Interface

PROGRAMMING, VERIFYING, AND ERASING THE 8742 EPROM

Programming Verification

In brief, the programming process consists of: activating the program mode, applying an address, latching the address, applying data, and applying a programming pulse. Each word is programmed completely before moving on to the next and is followed by a verification step. The following is a list of the pins used for programming and a description of their functions:

Pin	Function
XTAL 1	Clock Input
$\overline{\text{Reset}}$	Initialization and Address Latching
Test 0	Selection of Program or Verify Mode
EA	Activation of Program/Verify Modes
BUS	Address and Data Input Data Output During Verify
P20-12	Address Input
V_{DD}	Programming Power Supply
PROG	Program Pulse Input

WARNING

An attempt to program a missocketed 8742 will result in severe damage to the part. An indication of a properly socketed part is the appearance of the SYNC clock output. The lack of this clock may be used to disable the programmer.

The Program/Verify sequence is:

1. A_0 = 0V, CS = 5V, EA = 5V, RESET = 0V, TESTO = 5V, V_{DD} = 5V, clock applied or internal oscillator operating, BUS floating, PROG = 5V.
2. Insert 8742 in programming socket
3. TEST 0 = 0v (select program mode)
4. EA = 18V (active program mode)*
5. Address applied to BUS and $P_{20\text{-}22}$
6. $\overline{\text{RESET}}$ = 5v (latch address)
7. Data applied to BUS**
8. V_{DD} = 21V (programming power)**
9. PROG = V_{CC} followed by one 50 ms pulse to 18V**
10. V_{DD} = 5v
11. TEST 0 = 5v (verify mode)

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12. Read and verify data on BUS
13. TEST 0 = 0v
14. $\overline{RESET}$ = 0v and repeat from step 5
15. Programmer should be at conditions of step 1 when 8742 is removed from socket

*When verifying ROM, EA = 12V.
**Not used in verifying ROM procedure.

8742 Erasure Characteristics

The erasure characteristics of the 8742 are such that erasure begins to occur when exposed to light with wavelengtns shorter than approximately 4000 Angstroms (Å). It should be noted that sunlight and certain types of fluorescent lamps have wavelengths in the 3000-4000Å range. Data show that constant exposure to room level fluorescent lighting could erase the typical 8742 in approximately 3 years while it would take approximately one week to cause erasure when exposed to direct sunlight. If the 8742 is to be exposed to these types of lighting conditions for extended periods of time, opaque labels are available from Intel which should be placed over the 8742 window to prevent unintentional erasure.

The recommended erasure procedure for the 8742 is exposure to shortwave ultraviolet light which has a wavelength of 2537Å. The integrated dose (i.e., UV intensity × exposure time) for erasure should be a minimum of 15 w-sec/cm^2. The erasure time with this dosage is approximately 15 to 20 minutes using an ultraviolet lamp with a 12,000 μW/cm^2 power rating. The 8742 should be placed within one inch of the lamp tubes during erasure. Some lamps have a filter on their tubes which should be removed before erasure.

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias . . . . . 0°C to 70°C
Storage Temperature . . . . . −65°C to +150°C
Voltage on Any Pin With Respect
to Ground . . . . . −0.5V to +7V
Power Dissipation . . . . . 1.5 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS ($T_A = 0°$ to $+70°C$, $V_{CC} = V_{DD} = +5V \pm 10\%$)

Symbol	Parameter	8042/8742/8642 Min.	8042/8742/8642 Max.	Units	Notes
V_{IL}	Input Low Voltage (Except XTAL1, XTAL2, RESET)	−0.5	0.8	V	
V_{IL1}	Input Low Voltage (XTAL1, XTAL2, RESET)	−0.5	0.6	V	
V_{IH}	Input High Voltage (Except XTAL1, XTAL2, RESET)	2.0	V_{CC}	V	
V_{IH1}	Input High Voltage (XTAL1, XTAL2, RESET)	3.5	V_{CC}	V	
V_{OL}	Output Low Voltage (D_0–D_7)		0.45	V	$I_{OL} = 2.0$ mA
V_{OL1}	Output Low Voltage ($P_{10}P_{17}$, $P_{20}P_{27}$, Sync)		0.45	V	$I_{OL} = 1.6$ mA
V_{OL2}	Output Low Voltage (PROG)		0.45	V	$I_{OL} = 1.0$ mA
V_{OH}	Output High V. oltage (D_0–D_7)	2.4		V	$I_{OH} = -400\ \mu A$
V_{OH1}	Output High Voltage (All Other Outputs)	2.4			$I_{OH} = -50\ \mu A$
I_{IL}	Input Leakage Current (T_0, T_1, RD, WR, CS, A_0, EA)		± 10	μA	$V_{SS} \leq V_{IN} \leq V_{CC}$
I_{OFL}	Output Leakage Current (D_0–D_7, High Z State)		± 10	μA	$V_{SS} + 0.45 \leq V_{OUT} \leq V_{CC}$
I_{LI}	Low Input Load Current ($P_{10}P_{17}$, $P_{20}P_{27}$)		0.3	mA	$V_{IL} = 0.8V$
I_{LI1}	Low Input Load Current (RESET, SS)		0.2	mA	$V_{IL} = 0.8V$
I_{DD}	V_{DD} Supply Current		10	mA	Typical = 5 mA
$I_{CC} + I_{DD}$	Total Supply Current		125	mA	Typical = 60 mA
I_{IH}	Input Leakage Current (P_{10}-P_{17}, P_{20}-P_{27})		100	μA	$V_{IN} = V_{CC}$
C_{IN}	Input Capacitance		10	pF	
$C_{I/O}$	I/O Capacitance		20	pF	

D.C. CHARACTERISTICS—PROGRAMMING ($T_A = 25°C \pm 5°C$, $V_{CC} = 5V \pm 5\%$, $V_{DD} = 21V \pm 0.5V$

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{DOH}	V_{DD} Program Voltage High Level	20.5	21.5	V	
V_{DDL}	V_{DD} Voltage Low Level	4.75	5.25	V	
V_{PH}	PROG Program Voltage High Level	17.5	18.5	V	
V_{PL}	PROG Voltage Low Level	V_{CC}−0.5	V_{CC}	V	
V_{EAH}	EA Program or Verify Voltage High Level	17.5	18.5	V	
V_{EAL}	EA Voltage Low Level		5.25	V	
I_{DD}	V_{DD} High Voltage Supply Current		30.0	mA	
I_{PROG}	PROG High Voltage Supply Current		1.0	mA	
I_{EA}	EA High Voltage Supply Current		1.0	mA	

A.C. CHARACTERISTICS (T_A=0°C to +70°C, V_{SS}=0V, V_{CC}=V_{DD}=+5V ± 10%)

DBB READ

Symbol	Parameter	8042 Min.	8042 Max.	8642/8742 Min.	8642/8742 Max.	Units
t_{AR}	CS, A_0 Setup to RD↓	0		0		ns
t_{RA}	CS, A_0 Hold After RD↑	0		0		ns
t_{RR}	RD Pulse Width	160		160		ns
t_{AD}	CS, A_0 to Data Out Delay		130		130	ns
t_{RD}	RD↓ to Data Out Delay		130		130	ns
t_{DF}	RD↑ to Data Float Delay		85		85	ns
t_{CY}	Cycle Time	1.25	15	1.25	15	μs[1]

DBB WRITE

Symbol	Parameter	Min.	Max.	Min.	Max.	Units
t_{AW}	CS, A_0 Setup to WR↓	0		0		ns
t_{WA}	CS, A_0 Hold After WR↑	0		0		ns
t_{WW}	WR Pulse Width	160		160		ns
t_{DW}	Data Setup to WR↑	130		130		ns
t_{WD}	Data Hold After WR↑	0		0		ns

NOTE:
1. T_{CY} = 15/f(XTAL)

A.C. CHARACTERISTICS (T_A=25°C±5°C, V_{CC}=5V±5%, V_{DD}=21V ±0.5V)

PROGRAMMING

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AW}	Address Setup Time to RESET↑	$4t_{CY}$			
t_{WA}	Address Hold Time After RESET↑	$4t_{CY}$			
t_{DW}	Data in Setup Time to PROG↑	$4t_{CY}$			
t_{WD}	Data in Hold Time After PROG↓	$4t_{CY}$			
t_{PH}	RESET Hold Time to Verify	$4t_{CY}$			
t_{VDDW}	V_{DD} Setup Time to PROG↑	0	1.0	mS	
t_{VDDH}	V_{DD} Hold Time After PROG↑	0	1.0	mS	
t_{PW}	Program Pulse Width	50	60	mS	
t_{TW}	Test 0 Setup Time for Program Mode	$4t_{CY}$			
t_{WT}	Test 0 Hold Time After Program Mode	$4t_{CY}$			
t_{DO}	Test 0 to Data Out Delay		$4t_{CY}$		
t_{WW}	RESET Pulse Width to Latch Address	$4t_{CY}$			
t_r, t_f	V_{DD} and PROG Rise and Fall Times	0.5	2.0	μs	
t_{CY}	CPU Operation Cycle Time	4.0		μs	
t_{RE}	RESET Setup Time Before EA↑	$4t_{CY}$			

NOTE:
If TEST 0 is high, t_{DO} can be triggered by RESET↑.

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A.C. CHARACTERISTICS DMA

Symbol	Parameter	8042 Min.	8042 Max.	8642/8742 Min.	8642/8742 Max.	Units
t_{ACC}	DACK to WR or RD	0		0		ns
t_{CAC}	RD or WR to DACK	0		0		ns
t_{ACD}	DACK to Data Valid		130		130	ns
t_{CRQ}	RD or WR to DRQ Cleared		100		100	ns[1]

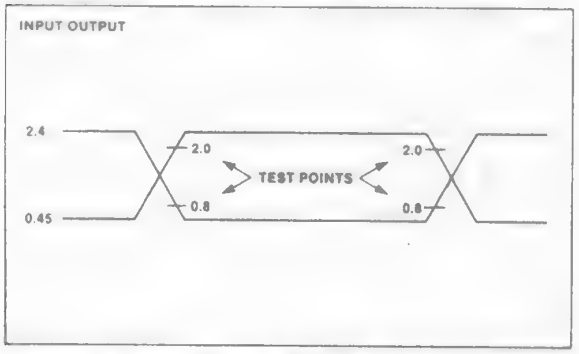
NOTE:
1. $C_L = 150$ pF.

A.C. CHARACTERISTICS PORT 2 ($T_A = 0°C$ to $+70°C$, $V_{CC} = +5V \pm 10\%$)

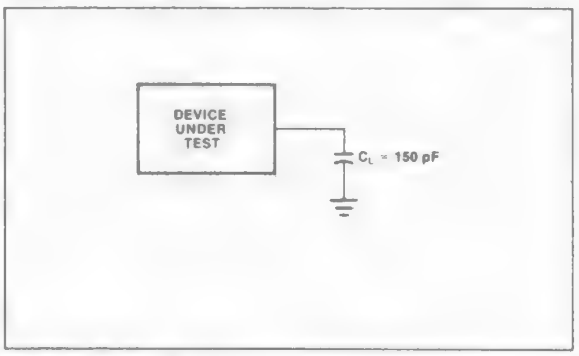
Symbol	Parameter	$f(t_{CY})$	8042/8742/8642[3] Min.	8042/8742/8642[3] Max.	Units
t_{CP}	Port Control Setup Before Falling Edge of PROG	$1/15\ t_{CY}-28$	55		ns[1]
t_{PC}	Port Control Hold After Falling Edge of PROG	$1/10\ t_{CY}$	125		ns[2]
t_{PR}	PROG to Time P2 Input Must Be Valid	$18/15\ t_{CY}-16$		650	ns[1]
t_{PF}	Input Data Hold Time		0	150	ns[2]
t_{DP}	Output Data Setup Time	$2/10\ T_{CY}$	250		ns[1]
t_{PD}	Output Data Hold Time	$1/10\ t_{CY}-80$	45		ns[2]
t_{PP}	PROG Pulse Width	$6/10\ t_{CY}$	750		ns

NOTES:
1. $C_L = 80$ pF.
2. $C_L = 20$ pF.
3. $t_{CY} = 1.25\ \mu s$.

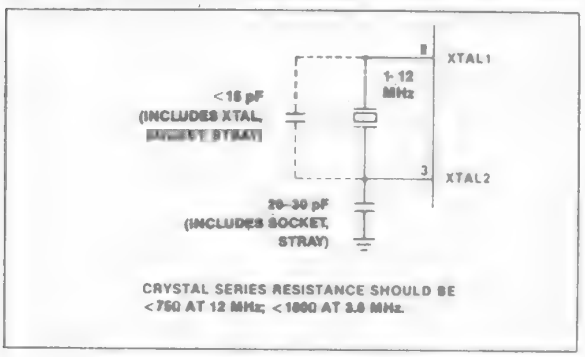
A.C. TESTING INPUT, OUTPUT WAVEFORM



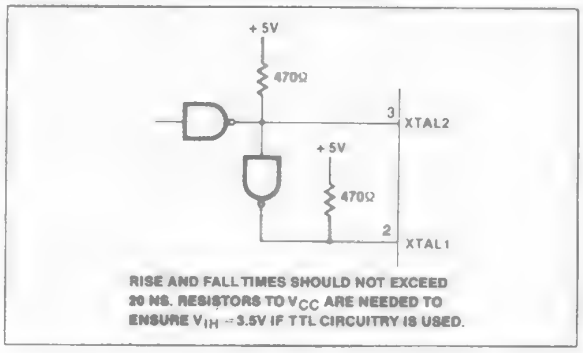
A.C. TESTING LOAD CIRCUIT



CRYSTAL OSCILLATOR MODE



DRIVING FROM EXTERNAL SOURCE



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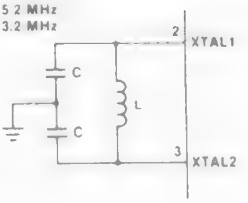
LC OSCILLATOR MODE

L	C	NOMINAL f
45 μH	20 pF	5.2 MHz
120 μH	20 pF	3.2 MHz



$$f = \frac{1}{2\pi\sqrt{LC'}}$$

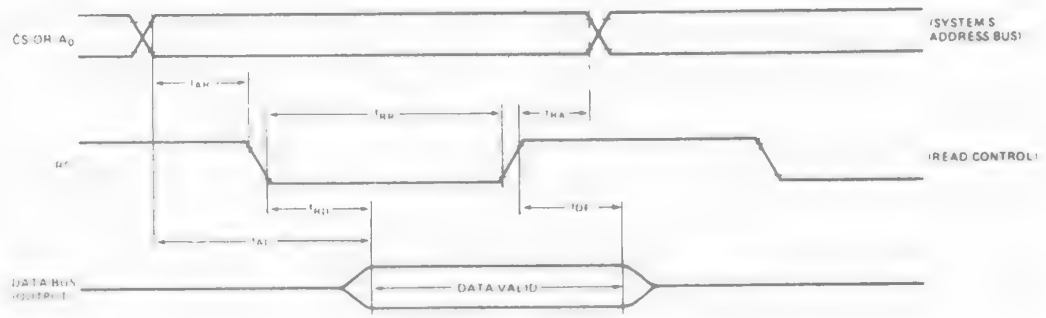
$$C' = \frac{C + 3C_{PP}}{2}$$

$C_{PP} \approx 5 - 10$ pF PIN TO PIN CAPACITANCE

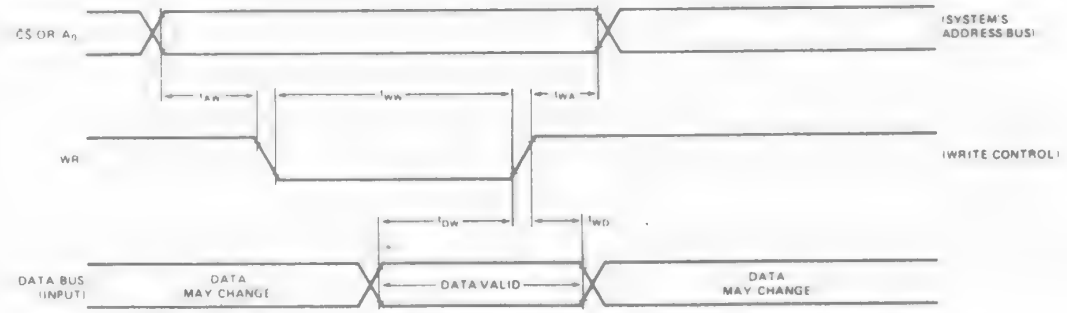
EACH C SHOULD BE APPROXIMATELY 20 pF, INCLUDING STRAY CAPACITANCE

WAVEFORMS

READ OPERATION—DATA BUS BUFFER REGISTER



WRITE OPERATION—DATA BUS BUFFER REGISTER



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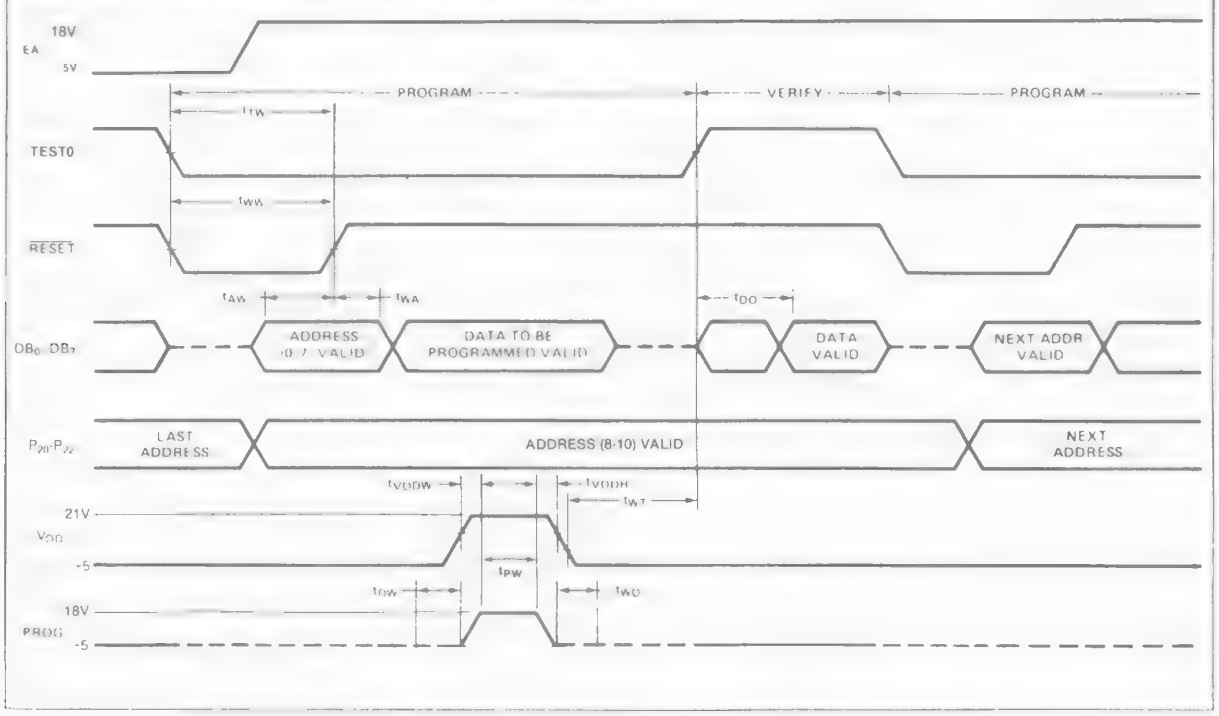
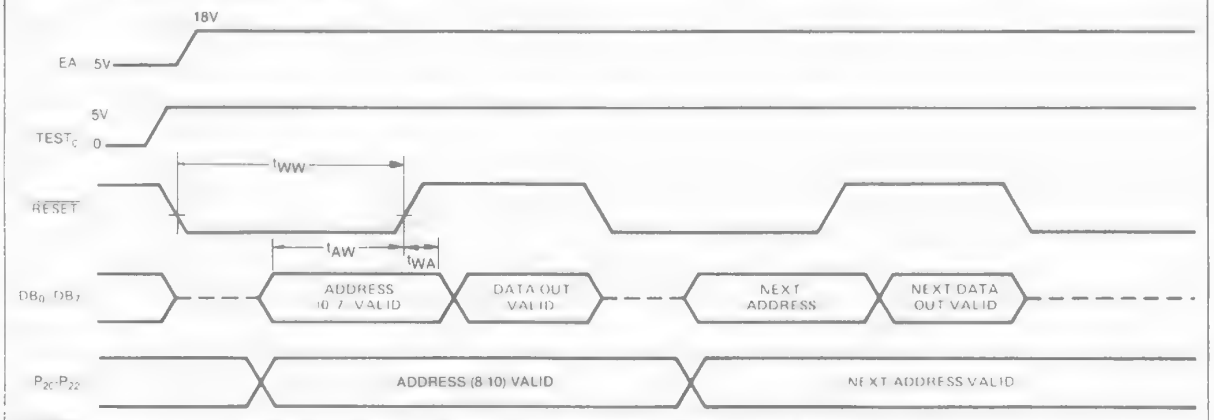
WAVEFORMS (Continued)

COMBINATION PROGRAM/VERIFY MODE (EPROM'S ONLY)



VERIFY MODE (ROM/EPROM)



NOTES:
1. PROG MUST FLOAT IF EA IS LOW OR IF $TEST_0$ = 5V FOR THE 8742. FOR THE 8042 PROG MUST ALWAYS FLOAT
2. A_0 MUST BE HELD LOW (i.e. = 0V) DURING PROGRAM/VERIFY MODES.
3. TEST 0 MUST BE HELD HIGH.

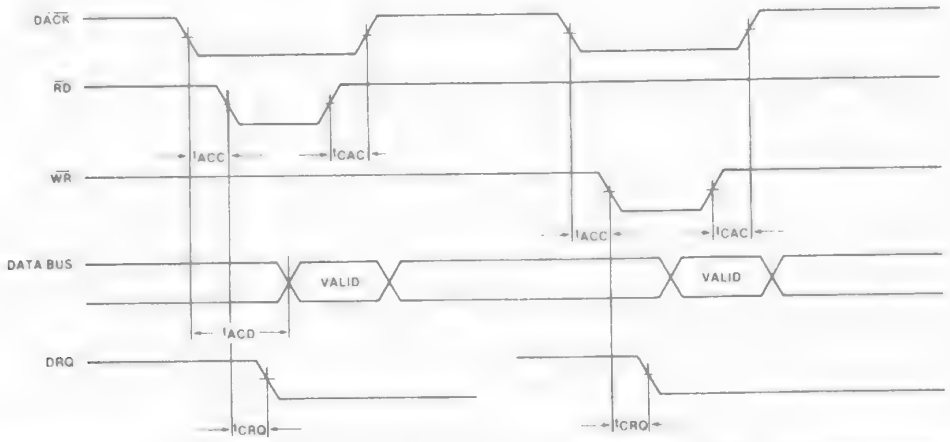
The 8742 EPROM can be programmed by the following Intel products:

1. Universal PROM Programmer (UPP 103) peripheral of the Intellec® Development System with a UPP-549 Personality Card.
2. iUP-200/iUP-201 PROM Programmer with the iUP-F87/44 Personality Module.

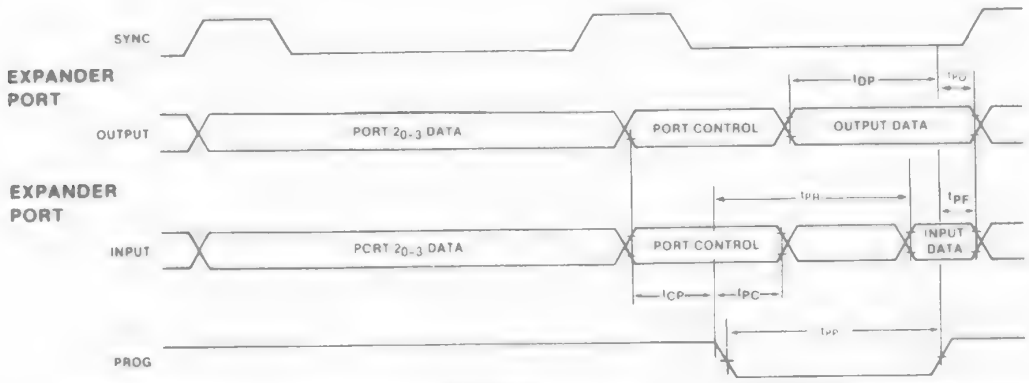
AFN-01832A

WAVEFORMS (Continued)

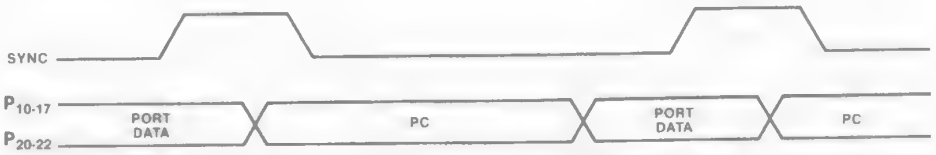
DMA



PORT 2



PORT TIMING DURING EA



ON THE RISING EDGE OF SYNC AND EA IS ENABLED PORT DATA IS VALID AND CAN BE STROBED ON THE TRAILING EDGE OF SYNC THE PROGRAM COUNTER CONTENTS ARE AVAILABLE

AFN-01832A

Table 2. UPI™ Instruction Set

Mnemonic	Description	Bytes	Cycles
ACCUMULATOR			
ADD A, Rr	Add register to A	1	1
ADD A, @Rr	Add data memory to A	1	1
ADD A, #data	Add immediate to A	2	2
ADDC A, Rr	Add register to A with carry	1	1
ADDC A, @Rr	Add data memory to A with carry	1	1
ADDC A, #data	Add immediate to A with carry	2	2
ANL A, Rr	AND register to A	1	1
ANL A, @Rr	AND data memory to A	1	1
ANL A, #data	AND immediate to A	2	2
ORL A, Rr	OR register to A	1	1
ORL A, @Rr	OR data memory to A	1	1
ORL A, #data	OR immediate to A	2	2
XRL A, Rr	Exclusive OR register to A	1	1
XRL A, @Rr	Exclusive OR data memory to A	1	1
XRL A, #data	Exclusive OR immediate to A	2	2
INC A	Increment A	1	1
DEC A	Decrement A	1	1
CLR A	Clear A	1	1
CPL A	Complement A	1	1
DA A	Decimal Adjust A	1	1
SWAP A	Swap nibbles of A	1	1
RL A	Rotate A left	1	1
RLC A	Rotate A left through carry	1	1
RR A	Rotate A right	1	1
RRC A	Rotate A right through carry	1	1
INPUT/OUTPUT			
IN A, Pp	Input port toA	1	2
OUTL Pp, A	Output A to port	1	2
ANL Pp, #data	AND immediate to port	2	2
ORL Pp, #data	OR immediate to port	2	2
IN A, DBB	Input DBB to A, clear IBF	1	1
OUT DBB, A	Output A to DBB, set OBF	1	1
MOV STS, A	A_4–A_7 to Bits 4–7 of Status	1	1
MOVD A, Pp	Input Expander port to A	1	2
MOVD Pp, A	Output A to Expander port	1	2
ANLD Pp, A	AND A to Expander port	1	2
ORLD Pp, A	OR A to Expander port	1	2

Mnemonic	Description	Bytes	Cycles
DATA MOVES			
MOV A, Rr	Move register to A	1	1
MOV A, @Rr	Move data memory to A	1	1
MOV A, #data	Move immediate TO A	2	2
MOV Rr, A	Move A to register	1	1
MOV @Rr, A	Move A to data memory	1	1
MOV Rr, #data	Move immediate to register	2	2
MOV @Rr, #data	Move immediate to data memory	2	2
MOV A, PSW	Move PSW to A	1	1
MOV PSW, A	Move A to PSW	1	1
XCH A, Rr	Exchange A and register	1	1
XCH A, @Rr	Exchange A and data memory	1	1
XCHD A, @Rr	Exchange digit of A and register	1	1
MOVP A, @A	Move to A from current page	1	2
MOVP3, A, @A	Move to A from page 3	1	2
TIMER/COUNTER			
MOV A, T	Read Timer/Counter	1	1
MOV T, A	Load Timer/Counter	1	1
STRT T	Start Timer	1	1
STRT CNT	start Counter	1	1
STOP TCNT	Stop Timer/Counter	1	1
EN TCNTI	Enable Timer/Counter Interrupt	1	1
DIS TCNTI	Disable Timer/Counter Interrupt	1	1
CONTROL			
EN DMA	Enable DMA Handshake Lines	1	1
EN I	Enable IBF Interrupt	1	1
DIS I	Disable IBF Interrupt	1	1
EN FLAGS	Enable Master Interrupts	1	1
SEL RB0	Select register bank 0	1	1
SEL RB1	Select register bank 1	1	1
NOP	No Operation	1	1
REGISTERS			
INC Rr	Increment register	1	1
INC @Rr	Increment data memory	1	1
DEC Rr	Decrement register	1	1
SUBROUTINE			
CALL addr	Jump to subroutine	2	2
RET	Return	1	2
RETR	Return and restore status	1	2

Table 2. UPI™ Instruction Set (Continued)

Mnemonic	Description	Bytes	Cycles
FLAGS			
CLR C	Clear Carry	1	1
CPL C	Complement Carry	1	1
CLR F0	Clear Flag 0	1	1
CPL F0	Complement Flag 0	1	1
CLR F1	Clear F1 Flag	1	1
CPL F1	Complement F1 Flag	1	1
BRANCH			
JMP addr	Jump unconditional	2	2
JMPP @A	Jump indirect	1	2
DJNZ Rr, addr	Decrement register and jump	2	2
JC addr	Jump on Carry=1	2	2
JNC addr	Jump on Carry=0	2	2
JZ addr	Jump on A Zero	2	2
JNZ addr	Jump on A not Zero	2	2
JT0 addr	Jump on T0=1	2	2
JNT0 addr	Jump on T0=0	2	2
JT1 addr	Jump on T1=1	2	2
JNT1 addr	Jump on T1=0	2	2
JF0 addr	Jump on F0 Flag=1	2	2
JF1 addr	Jump on F1 Flag=1	2	2
JTF addr	Jump on Timer Flag =1, Clear Flag	2	2
JNIBF addr	Jump on IBF Flag =0	2	2
JOBF addr	Jump on OBF Flag =1	2	2
JBb addr	Jump on Accumulator Bit	2	2

PRELIMINARY

8202A
DYNAMIC RAM CONTROLLER

- **Provides All Signals Necessary to Control 2117, or 2118 Dynamic Memories**
- **Directly Addresses and Drives Up to 64K Bytes Without External Drivers**
- **Provides Address Multiplexing and Strobes**
- **Provides a Refresh Timer and a Refresh Counter**
- **Refresh Cycles May be Internally or Externally Requested**
- **Provides Transparent Refresh Capability**
- **Fully Compatible with Intel® 8080A, 8085A, iAPX 88, and iAPX 86 Family Microprocessors**
- **Decodes CPU Status for Advanced Read Capability with the 8202A-1 or 8202A-3**
- **Provides System Acknowledge and Transfer Acknowledge Signals**
- **Internal Clock Capability with the 8202A-1 or 8202A-3**

The Intel® 8202A is a Dynamic Ram System Controller designed to provide all signals necessary to use 2117 or 2118 Dynamic RAMs in microcomputer systems. The 8202A provides multiplexed addresses and address strobes, as well as refresh/access arbitration. The 8202A-1 or 8202A-3 support an internal crystal oscillator.

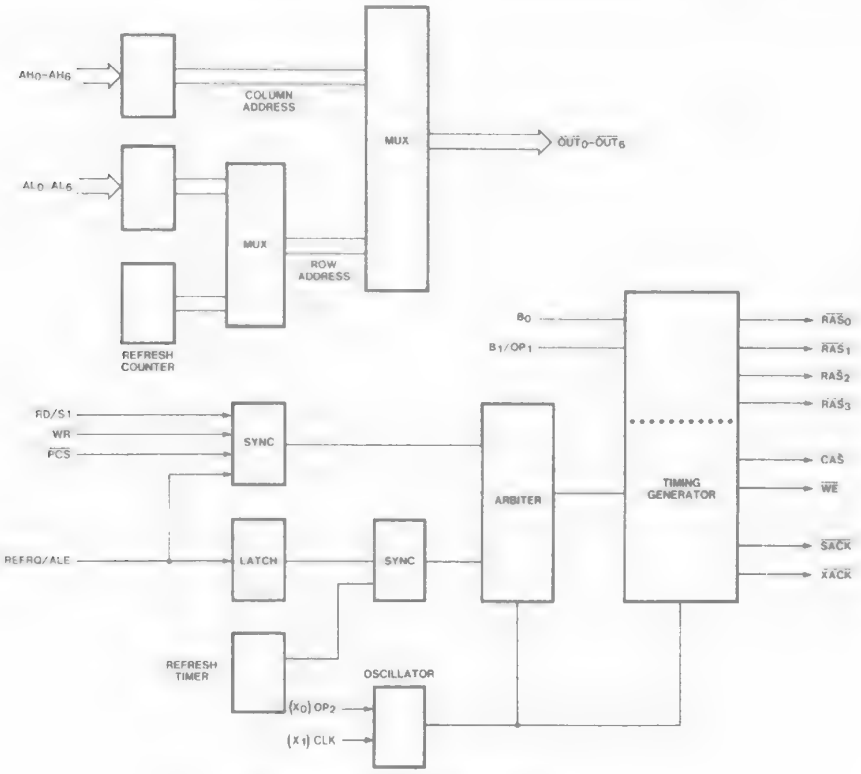


Figure 1. 8202A Block Diagram

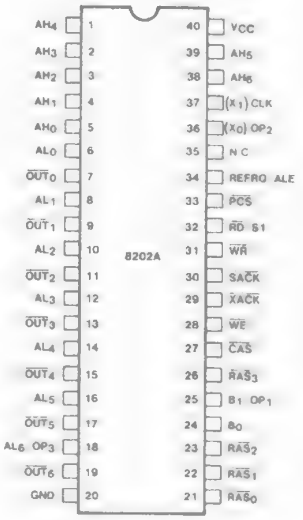


Figure 2. Pin Configuration

Table 1. Pin Descriptions

Symbol	Pin No.	Type	Name and Function
AL_0 AL_1 AL_2 AL_3 AL_4 AL_5 AL_6	6 8 10 12 14 16 18	I I I I I I I	**Address Low:** CPU address inputs used to generate memory row address.
AH_0 AH_1 AH_2 AH_3 AH_4 AH_5 AH_6	5 4 3 2 1 39 38	I I I I I I I	**Address High:** CPU address inputs used to generate memory column address.
BO B_1/OP_1	24 25	I I	**Bank Select Inputs:** Used to gate the appropriate RAS_0-RAS_3 output for a memory cycle. B_1/OP_1 option used to select the Advanced Read Mode.
$\overline{PCS}$	33	I	**Protected Chip Select:** Used to enable the memory read and write inputs. Once a cycle is started, it will not abort even if $\overline{PCS}$ goes inactive before cycle completion.
$\overline{WR}$	31	I	**Memory Write Request.**
$\overline{RD}/S1$	32	I	**Memory Read Request:** S1 function used in Advanced Read mode selected by OP_1 (pin 25).
REFRQ/ALE	34	I	**External Refresh Request:** ALE function used in Advanced Read mode, selected by OP_1 (pin 25).
$\overline{OUT}_0$ $\overline{OUT}_1$ $\overline{OUT}_2$ $\overline{OUT}_3$ $\overline{OUT}_4$ $\overline{OUT}_5$ $\overline{OUT}_6$	7 9 11 13 15 17 19	O O O O O O O	**Output of the Multiplexer:** These outputs are designed to drive the addresses of the Dynamic RAM array. For 4K RAM operation, $\overline{OUT}_6$ is designed to drive the 2104A $\overline{CS}$ input. (Note that the $\overline{OUT}_{0-6}$ pins do not require inverters or drivers for proper operation.
$\overline{WE}$	28	O	**Write Enable:** Drives the Write Enable inputs of the Dynamic RAM array.
$\overline{CAS}$	27	O	**Column Address Strobe:** This output is used to latch the Column Address into the Dynamic RAM array.
$\overline{RAS}_0$ $\overline{RAS}_1$ $\overline{RAS}_2$ $\overline{RAS}_3$	21 22 23 26	O O O O	**Row Address Strobe:** Used to latch the Row Address into the bank of dynamic RAMs, selected by the 8202A Bank Select pins (B_0, B_1/OP_1).
$\overline{XACK}$	29	O	**Transfer Acknowledge:** This output is a strobe indicating valid data during a read cycle or data written during a write cycle. $\overline{XACK}$ can be used to latch valid data from the RAM array.
$\overline{SACK}$	30	O	**System Acknowledge:** This output indicates the beginning of a memory access cycle. It can be used as an advanced transfer acknowledge to eliminate wait states. (Note: If a memory access request is made during a refresh cycle, $\overline{SACK}$ is delayed until $\overline{XACK}$ in the memory access cycle).
(X_0) OP_2 (X_1) CLK	36 37	I/O I/O	**Oscillator Inputs:** These inputs are designed for a quartz crystal to control the frequency of the oscillator. If X_0/OP_2 is connected to a 1KΩ resistor pulled to +12V then X_1/CLK becomes a TTL input for an external clock.
N.C.	35		Reserved for future use.
V_{CC}	40		**Power Supply:** +5V.
GND	20		**Ground.**

NOTE: Crystal mode for the 8202A-1 or 8202A-3 only.

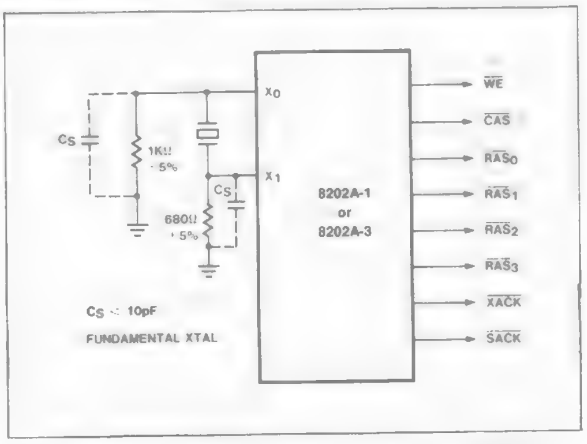


Figure 3. Crystal Operation for the 8202A-1 and the 8202A-3

Functional Description

The 8202A provides a complete dynamic RAM controller for microprocessor systems as well as expansion memory boards. All of the necessary control signals are provided for 2117 and 2118 dynamic RAMs.

All 8202A timing is generated from a single reference clock. This clock is provided via an external oscillator or an on chip crystal oscillator. All output signal transitions are synchronous with respect to this clock reference, except for the CPU handshake signals $\overline{SACK}$ and $\overline{XACK}$ (trailing edge).

CPU memory requests normally use the $\overline{RD}$ and $\overline{WR}$ inputs. The advanced READ mode allows ALE and S1 to be used in place of the $\overline{RD}$ input.

Failsafe refresh is provided via an internal refresh timer which generates internal refresh requests. Refresh requests can also be generated via the REFRQ input.

An on-chip synchronizer/arbiter prevents memory and refresh requests from affecting a cycle in progress. The READ, WRITE, and external REFRESH requests may be asynchronous to the 8202A clock; on-chip logic will synchronize the requests, and the arbiter will decide if the requests should be delayed, pending completion of a cycle in progress.

Option Selection

The 8202A has three strapping options. When OP_1 is selected (16K mode only), pin 32 changes from a $\overline{RD}$ input to an S1 input, and pin 34 changes from a REFREQ input to an ALE input. See "Refresh Cycles" and "Read Cycles" for more detail. OP_1 is selected by tying pin 25 to +12V through a 5.1K ohm resistor on the 8202A-1 or 8202A-3 only.

When OP_2 is selected, by connecting pin 36 to +12V through a 1K ohm resistor, pin 37 changes from a crystal input (X_1) to the CLK input for an external TTL clock.

Refresh Timer

The refresh timer is used to monitor the time since the last refresh cycle occurred. When the appropriate amount of time has elapsed, the refresh timer will request a refresh cycle. External refresh requests will reset the refresh timer.

Refresh Counter

The refresh counter is used to sequentially refresh all of the memory's rows. The 8-bit counter is incremented after every refresh cycle.

Address Multiplexer

The address multiplexer takes the address inputs and the refresh counter outputs, and gates them onto the address outputs at the appropriate time. The address outputs, in conjunction with the $\overline{RAS}$ and $\overline{CAS}$ outputs, determine the address used by the dynamic RAMs for read, write, and refresh cycles. During the first part of a read or write cycle, AL_0–AL_6 are gated to $\overline{OUT}_0$–$\overline{OUT}_6$, then AH_0–AH_6 are gated to the address outputs.

During a refresh cycle, the refresh counter is gated onto the address outputs. All refresh cycles are RAS-only refresh ($\overline{CAS}$ inactive, $\overline{RAS}$ active).

To minimize buffer delay, the information on the address outputs is inverted from that on the address inputs.

$\overline{OUT}_0$–$\overline{OUT}_6$ do not need inverters or buffers unless additional drive is required.

Synchronizer/Arbiter

The 8202A has three inputs, REFRQ/ALE (pin 34), $\overline{RD}$ (pin 32) and $\overline{WR}$ (pin 31). The $\overline{RD}$ and $\overline{WR}$ inputs allow an external CPU to request a memory read or write cycle, respectively. The REFRQ/ALE allows refresh requests to be requested external to the 8202A.

All three of these inputs may be asynchronous with respect to the 8202A's clock. The arbiter will resolve conflicts between refresh and memory requests, for both pending cycles and cycles in progress. Read and write requests will be given priority over refresh requests.

System Operation

The 8202A is always in one of the following states:

a) IDLE
b) TEST Cycle
c) REFRESH Cycle
d) READ Cycle
e) WRITE Cycle

The 8202A is normally in the IDLE state. Whenever one of the other cycles is requested, the 8202A will leave the IDLE state to perform the desired cycle. If no other cycles are pending, the 8202A will return to the IDLE state.

Description	Pin #	Normal Function	Option Function
B1/OP1	25	Bank (RAS) Select	Advanced-Read Mode (see text)
X_0/OP_2	36	Crystal Oscillator (8202A-1 or 8202A-3)	External Oscillator

Figure 4. 8202A Option Selection

Test Cycle

The TEST Cycle is used to check operation of several 8202A internal functions. TEST cycles are requested by activating the $\overline{RD}$ and $\overline{WR}$ inputs, independent of $\overline{PCS}$. The TEST Cycle will reset the refresh address counter. It will perform a WRITE Cycle if $\overline{PCS}$ is low. The TEST Cycle should not be used in normal system operation, since it would affect the dynamic RAM refresh.

Refresh Cycles

The 8202A has two ways of providing dynamic RAM refresh:

1) Internal (failsafe) refresh
2) External (hidden) refresh

Both types of 8202A refresh cycles activate all of the $\overline{RAS}$ outputs, while $\overline{CAS}$, $\overline{WE}$, $\overline{SACK}$, and $\overline{XACK}$ remain inactive.

Internal refresh is generated by the on-chip refresh timer. The timer uses the 8202A clock to ensure that refresh of all rows of the dynamic RAM occurs every 2 milliseconds. If REFRQ is inactive, the refresh timer will request a refresh cycle every 10-16 microseconds.

External refresh is requested via the REFRQ input (pin 34). External refresh control is not available when the Advanced-Read mode is selected. External refresh requests are latched, then synchronized to the 8202A clock.

The arbiter will allow the refresh request to start a refresh cycle only if the 8202A is not in the middle of a cycle.

Simultaneous memory request and external refresh request will result in the memory request being honored first. This 8202A characteristic can be used to "hide" refresh cycles during system operation. A circuit similar to Figure 5 can be used to decode the CPU's instruction fetch status to generate an external refresh request. The refresh request is latched while the 8202A performs the instruction fetch; the refresh cycle will start immediately after the memory cycle is completed, even if the $\overline{RD}$ input has not gone inactive. If the CPU's instruction decode time is long enough, the 8202A can complete the refresh cycle before the next memory request is generated.

Certain system configurations require complete external refresh requests. If external refresh is requested faster than the minimum internal refresh timer (t_{REF}), then, in effect, all refresh cycles will be caused by the external refresh request, and the internal refresh timer will never generate a refresh request.

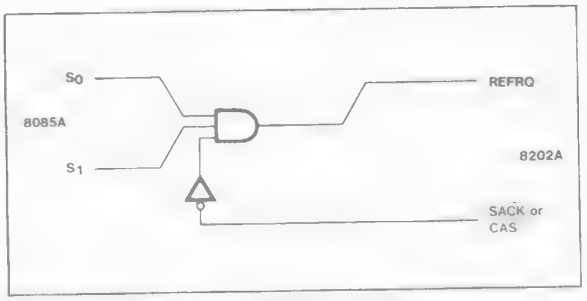


Figure 5. Hidden Refresh

Read Cycles

The 8202A can accept two different types of memory Read requests:

1) Normal Read, via the $\overline{RD}$ input
2) Advanced Read, using the S1 and ALE inputs

The user can select the desired Read request configuration via the B1/OP1 hardware strapping option on pin 25.

	Normal Read	Advanced Read
Pin 25	B1 input	+12 Volt Option
Pin 32	RD input	S1 input
Pin 34	REFRQ input	ALE input
# RAM banks	4 ($\overline{RAS}_{0-3}$)	2 ($\overline{RAS}_{2-3}$)
Ext. Refresh Req.	Yes	No

Figure 6. 8202A Read Options

Normal Reads are requested by activating the $\overline{RD}$ input, and keeping it active until the 8202A responds with an $\overline{XACK}$ pulse. The $\overline{RD}$ input can go inactive as soon as the command hold time (t_{CHS}) is met.

Advanced Read cycles are requested by pulsing ALE while S1 is active; if S1 is inactive (low) ALE is ignored. Advanced Read timing is similiar to Normal Read timing, except the falling edge of ALE is used as the cycle start reference.

If a Read cycle is requested while a refresh cycle is in progress, then the 8202A will set the internal delayed-SACK latch. When the Read cycle is eventually started, the 8202A will delay the active $\overline{SACK}$ transition until $\overline{XACK}$ goes active, as shown in the AC timing diagrams. This delay was designed to compensate for the CPU's READY setup and hold times. The delayed-SACK latch is cleared after every READ cycle.

Based on system requirements, either $\overline{SACK}$ or $\overline{XACK}$ can be used to generate the CPU READY signal. $\overline{XACK}$ will

normally be used; if the CPU can tolerate an advanced READY, then $\overline{SACK}$ can be used, but only if the CPU can tolerate the amount of advance provided by $\overline{SACK}$. If $\overline{SACK}$ arrives too early to provide the appropriate number of WAIT states, then either $\overline{XACK}$ or a delayed form of $\overline{SACK}$ should be used.

Write Cycles

Write cycles are similiar to Normal Read cycles, except for the $\overline{WE}$ output. $\overline{WE}$ is held inactive for Read cycles, but goes active for Write cycles. All 8202A Write cycles are "early-write" cycles; $\overline{WE}$ goes active before $\overline{CAS}$ goes active by an amount of time sufficient to keep the dynamic RAM output buffers turned off.

General System Considerations

All memory requests (Normal Reads, Advanced Reads, Writes) are qualified by the $\overline{PCS}$ input. $\overline{PCS}$ should be stable, either active or inactive, prior to the leading edge of $\overline{RD}$, $\overline{WR}$, or ALE. Systems which use battery backup should pullup $\overline{PCS}$ to prevent erroneous memory requests, and should also pullup $\overline{WR}$ to keep the 8202A out of its test mode.

In order to minimize propagation delay, the 8202A uses an inverting address multiplexer without latches. The system must provide adequate address setup and hold times to guarantee $\overline{RAS}$ and $\overline{CAS}$ setup and hold times for the RAM. The 8202A t_{AD} AC parameter should be used for this system calculation.

The B0-B1 inputs are similiar to the address inputs in that they are not latched. B0 and B1 should not be changed during a memory cycle, since they directly control which $\overline{RAS}$ output is activated.

The 8202A uses a two-stage synchronizer for the memory request inputs ($\overline{RD}$, $\overline{WR}$, ALE), and a separate two stage synchronizer for the external refresh input (REFRQ). As with any synchronizer, there is always a finite probability of metastable states inducing system errors. The 8202A synchronizer was designed to have a system error rate less than 1 memory cycle every three years based on the full operating range of the 8202A.

A microprocessor system is concerned with the time data is valid after $\overline{RD}$ goes low. See Figure 7. In order to calculate memory read access times, the dynamic RAM's A.C. specifications must be examined, especially the RAS-access time (t_{RAC}) and the CAS-access time (t_{CAC}). Most configurations will be CAS-access limited; i.e., the data from the RAM will be stable $t_{cc,max}$ (8202A) + t_{CAC} (RAM) after a memory read cycle is started. Be sure to add any delays (due to buffers, data latches, etc.) to calculate the overall read access time.

Since the 8202A normally performs "early-write" cycles, the data must be stable at the RAM data inputs by the time $\overline{CAS}$ goes active, including the RAM's data setup time. If the system does not normally guarantee sufficient write data setup, you must either delay the $\overline{WR}$ input signal or delay the 8202A $\overline{WE}$ output.

Delaying the $\overline{WR}$ input will delay all 8202A timing, including the READY handshake signals, $\overline{SACK}$ and $\overline{XACK}$, which may increase the number of WAIT states generated by the CPU.

If the $\overline{WE}$ output is externally delayed beyond the $\overline{CAS}$ active transition, then the RAM will use the falling edge of $\overline{WE}$ to strobe the write data into the RAM. This $\overline{WE}$ transition should not occur too late during the CAS active transition, or else the $\overline{WE}$ to $\overline{CAS}$ requirements of the RAM will not be met.

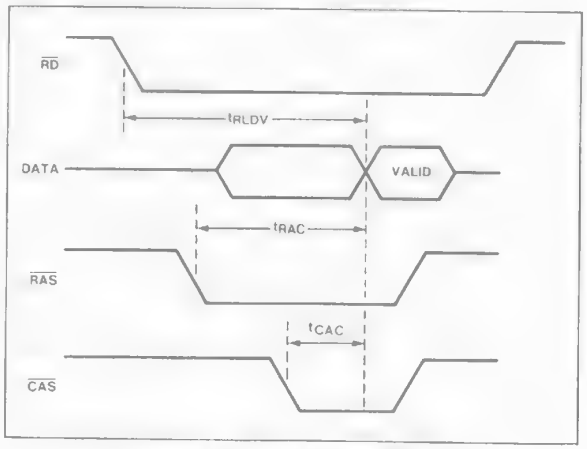


Figure 7. Read Access Time

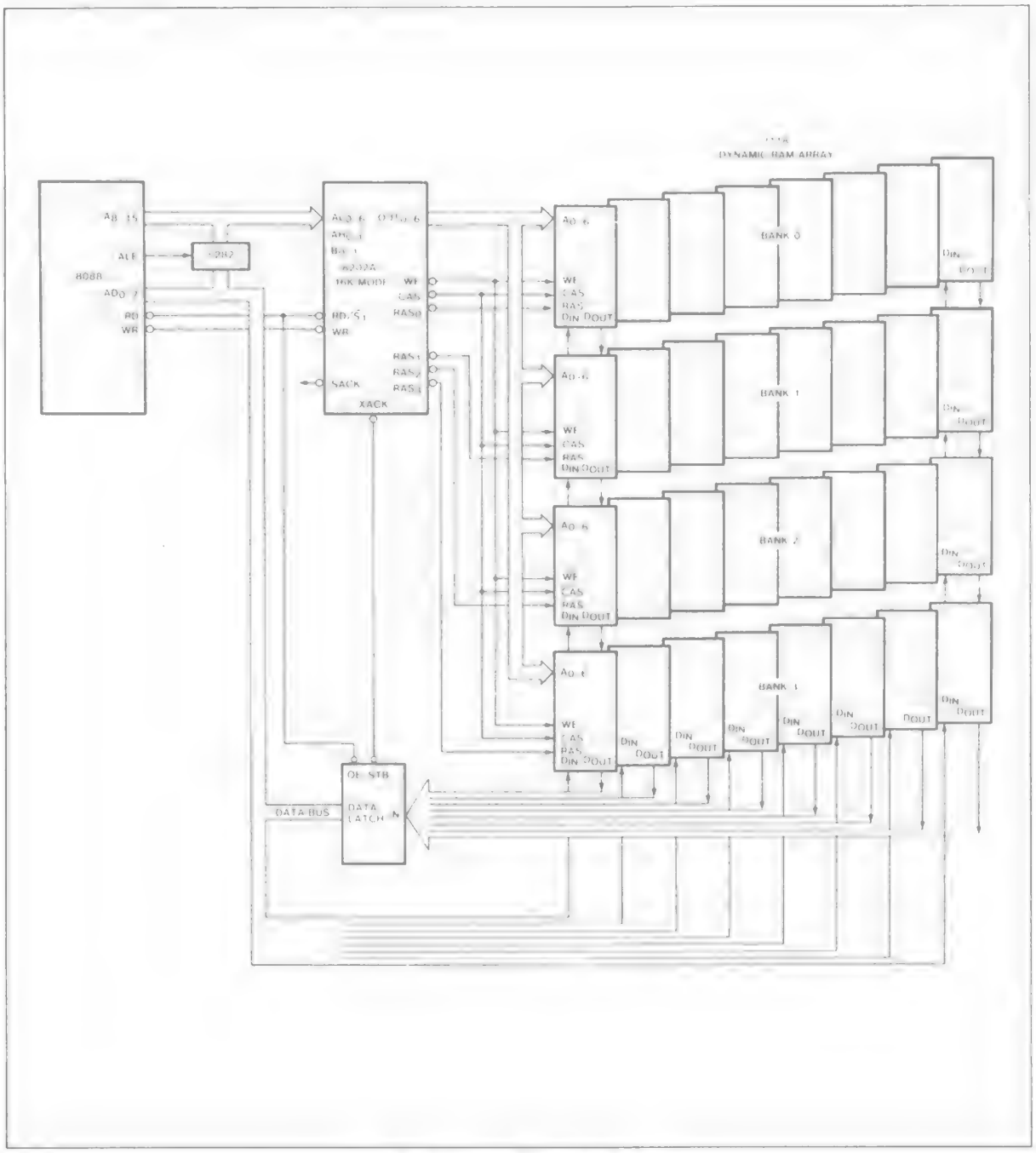


Figure 8. Typical 8088 System

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage On any Pin
With Respect to Ground ..... −0.5V to +7V[4]
Power Dissipation ..... 1.5 Watts

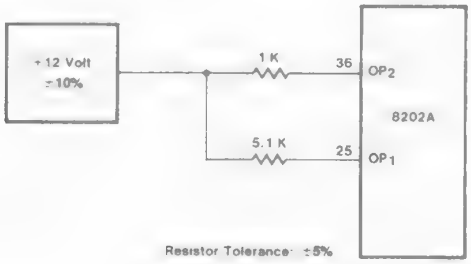
**NOTE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS

T_A = 0°C to 70°C; V_{CC} = 5.0V ± 10%, V_{CC} = 5.0V ± 5% for 8202A-3, GND = 0V

Symbol	Parameter	Min	Max	Units	Test Conditions
V_C	Input Clamp Voltage		−1.0	V	I_C = −5 mA
I_{CC}	Power Supply Current		270	mA	
I_F	Forward Input Current CLK All Other Inputs[3]		 −2.0 −320	 mA μA	 V_F = 0.45V V_F = 0.45V
I_R	Reverse Input Current[3]		40	μA	$V_R = V_{CC}$ (Note 1)
V_{OL}	Output Low Voltage $\overline{SACK}$, $\overline{XACK}$ All Other Outputs		 0.45 0.45	 V V	 I_{OL} = 5 mA I_{OL} = 3 mA
V_{OH}	Output High Voltage $\overline{SACK}$, $\overline{XACK}$ All Other Outputs	 2.4 2.6		 V V	V_{IL} = 0.65V I_{OH} = −1 mA I_{OH} = −1 mA
V_{IL}	Input Low Voltage		0.8	V	V_{CC} = 5.0V (Note 2)
V_{IH1}	Input High Voltage	2.0		V	V_{CC} = 5.0V
V_{IH2}	Option Voltage			V	(Note 4)
C_{IN}	Input Capacitance		30	pF	F = 1 MHz V_{BIAS} = 2.5V, V_{CC} = 5V T_A = 25°C

NOTES:
1. I_R = 200 mA for pin 37 (CLK) for external clock mode.
2. For test mode $\overline{RD}$ & $\overline{WR}$ must be held at GND.
3. Except for pin 36.
4.



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A.C. CHARACTERISTICS

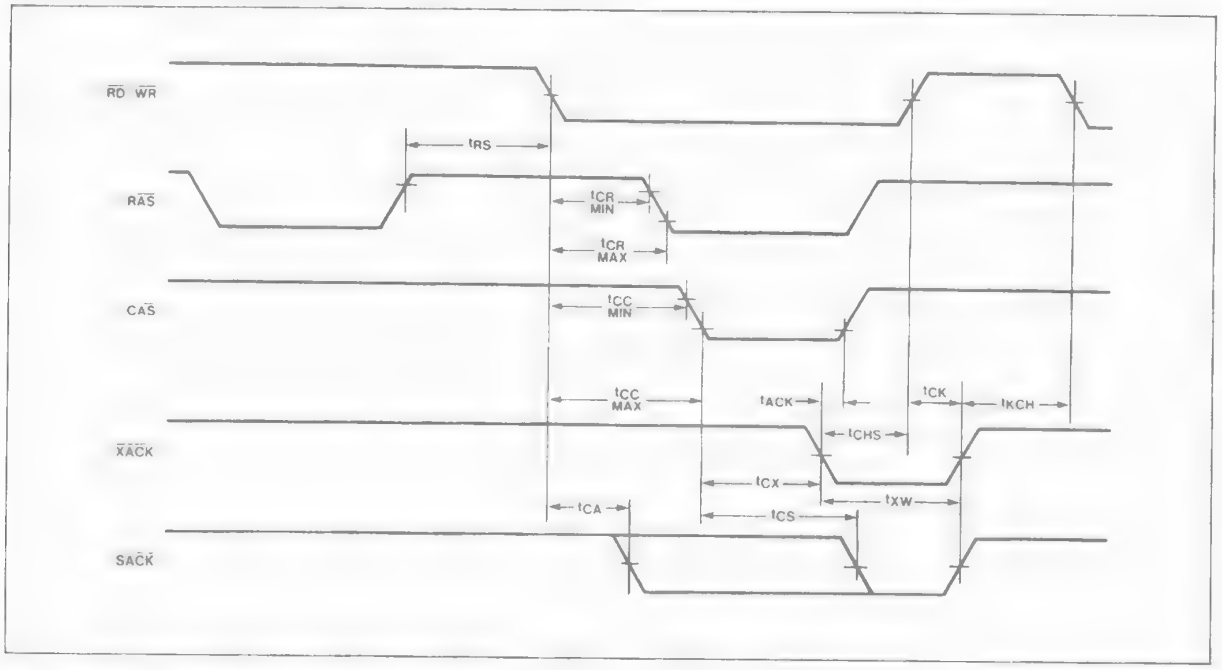
T_A = 0°C to 70°C, V_{CC} = 5V ± 10%, V_{CC} = 5V ± 5% for 8202A-3

Measurements made with respect to $\overline{RAS}_0$-$\overline{RAS}_3$, $\overline{CAS}$, $\overline{WE}$, $\overline{OUT}_0$-$\overline{OUT}_6$ are at 2.4V and 0.8V. All other pins are measured at 1.5V. All times are in nsec.

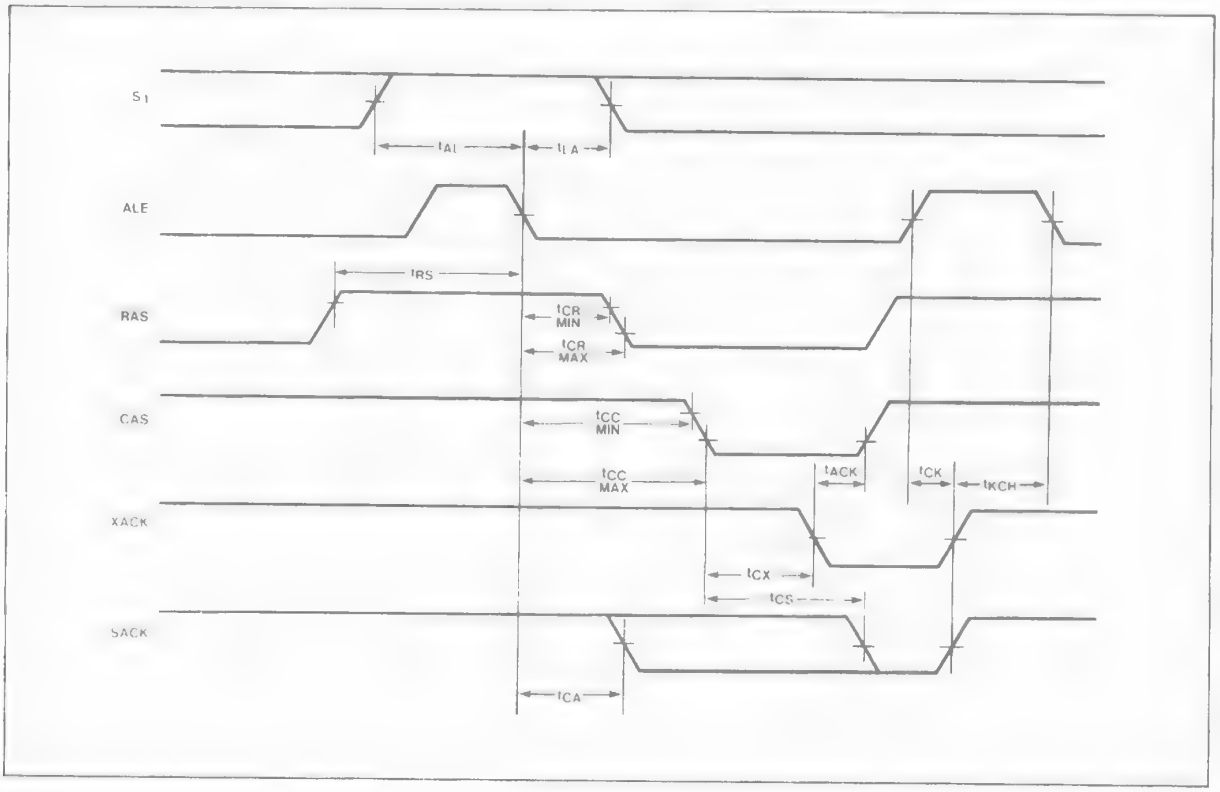
Symbol	Parameter	Min	Max	Notes
t_P	Clock Period	40	54	
t_{PH}	External Clock High Time	20		
t_{PL}	External Clock Low Time—above (>) 20 mHz	17		
t_{PL}	External Clock Low Time—below (<) 20 mHz	20		
t_{RC}	Memory Cycle Time	10tp − 30	12tp	4, 5
t_{REF}	Refresh Time (128 cycles—16K mode)	264tp	288tp	
t_{RP}	$\overline{RAS}$ Precharge Time	4tp − 30		
t_{RSH}	$\overline{RAS}$ Hold After $\overline{CAS}$	5tp − 30		3
t_{ASR}	Address Setup to $\overline{RAS}$	tp − 30		3
t_{RAH}	Address Hold From $\overline{RAS}$	tp − 10		3
t_{ASC}	Address Setup to $\overline{CAS}$	tp − 30		3
t_{CAH}	Address Hold from $\overline{CAS}$	5tp − 20		3
t_{CAS}	$\overline{CAS}$ Pulse Width	5tp − 10		
t_{WCS}	$\overline{WE}$ Setup to $\overline{CAS}$	tp − 40		
t_{WCH}	$\overline{WE}$ Hold After $\overline{CAS}$	5tp − 35		8
t_{RS}	$\overline{RD}$, $\overline{WR}$, ALE, REFRQ delay from $\overline{RAS}$	5tp		
t_{MRP}	$\overline{RD}$, $\overline{WR}$ setup to $\overline{RAS}$	0		5
t_{RMS}	REFRQ setup to $\overline{RD}$, $\overline{WR}$	2tp		
t_{RMP}	REFRQ setup to $\overline{RAS}$	2tp		5
t_{PCS}	$\overline{PCS}$ Setup to $\overline{RD}$, $\overline{WR}$, ALE	20		
t_{AL}	S1 Setup to ALE	15		
t_{LA}	S1 Hold from ALE	30		
t_{CR}	$\overline{RD}$, $\overline{WR}$, ALE to $\overline{RAS}$ Delay	tp + 30	2tp + 70	2
t_{CC}	$\overline{RD}$, $\overline{WR}$, ALE to $\overline{CAS}$ Delay	3tp + 25	4tp + 85	2
t_{SC}	CMD Setup to Clock	15		1
t_{MRS}	$\overline{RD}$, $\overline{WR}$ setup to REFRQ	5		
t_{CA}	$\overline{RD}$, $\overline{WR}$, ALE to $\overline{SACK}$ Delay		2tp + 47	2, 9
t_{CX}	$\overline{CAS}$ to $\overline{XACK}$ Delay	5tp − 25	5tp + 20	
t_{CS}	$\overline{CAS}$ to $\overline{SACK}$ Delay	5tp − 25	5tp + 40	2, 10
t_{ACK}	$\overline{XACK}$ to $\overline{CAS}$ Setup	10		
t_{XW}	$\overline{XACK}$ Pulse Width	tp − 25		7
t_{CK}	$\overline{SACK}$, $\overline{XACK}$ turn-off Delay		35	
t_{KCH}	CMD Inactive Hold after $\overline{SACK}$, $\overline{XACK}$	10		
t_{LL}	REFRQ Pulse Width	20		
t_{CHS}	CMD Hold Time	30		11
t_{RFR}	REFRQ to $\overline{RAS}$ Delay		4tp + 100	6
t_{WW}	$\overline{WR}$ to $\overline{WE}$ Delay	0	50	8
t_{AD}	CPU Address Delay	0	40	3

WAVEFORMS

Normal Read or Write Cycle



Advanced Read Mode



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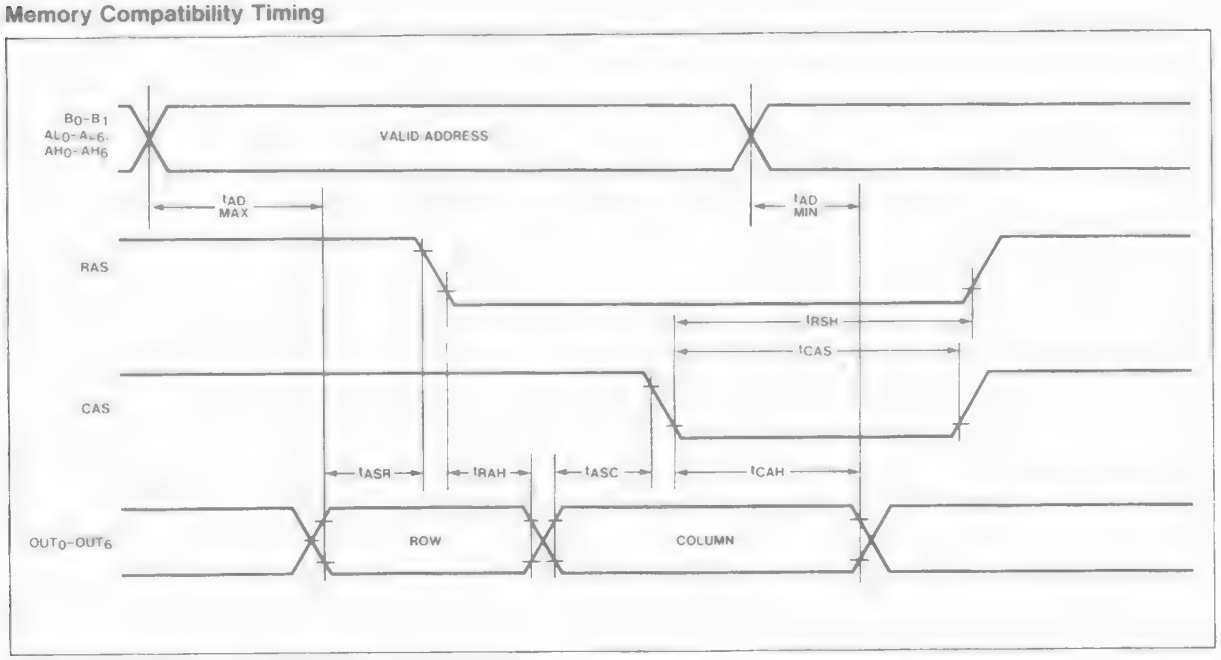
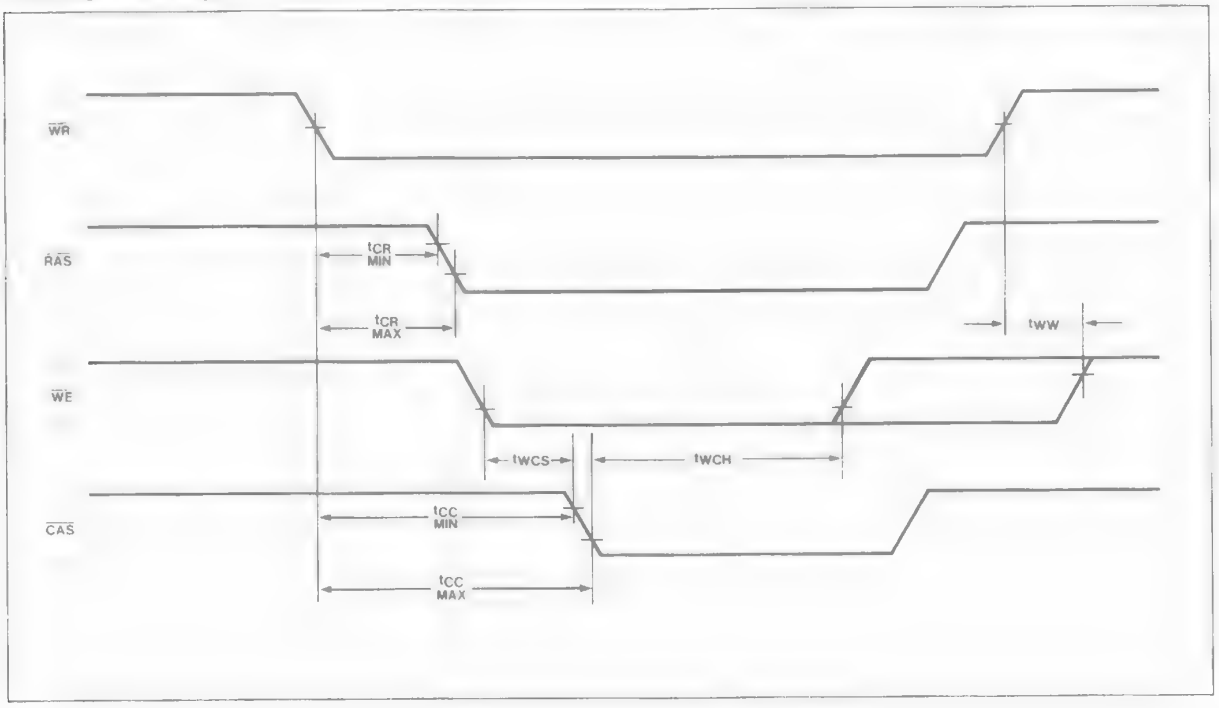
WAVEFORMS (cont'd)

Memory Compatibility Timing



Write Cycle Timing



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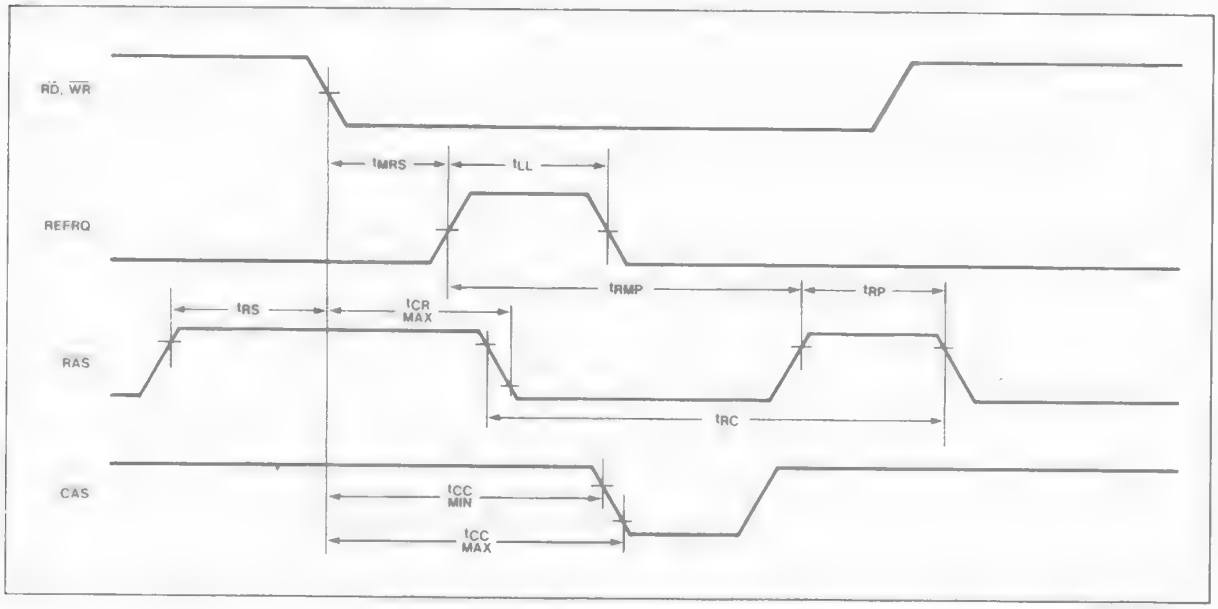
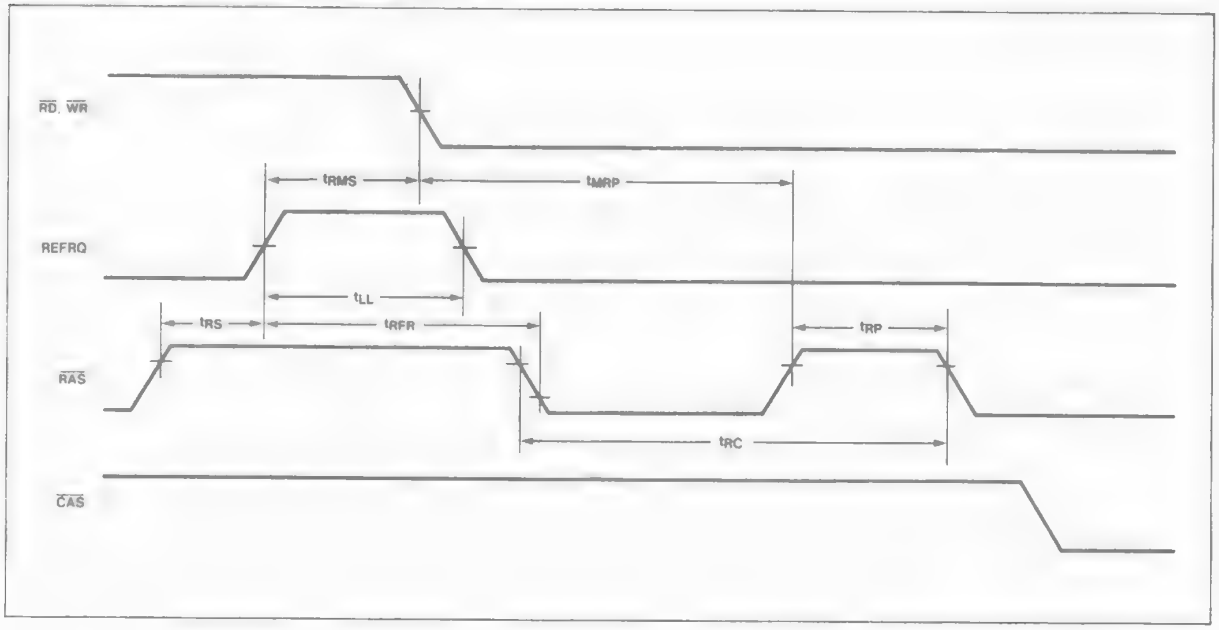
WAVEFORMS (cont'd)

Read or Write Followed By External Refresh



External Refresh Followed By Read or Write



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WAVEFORMS (cont'd)

Clock And System Timing

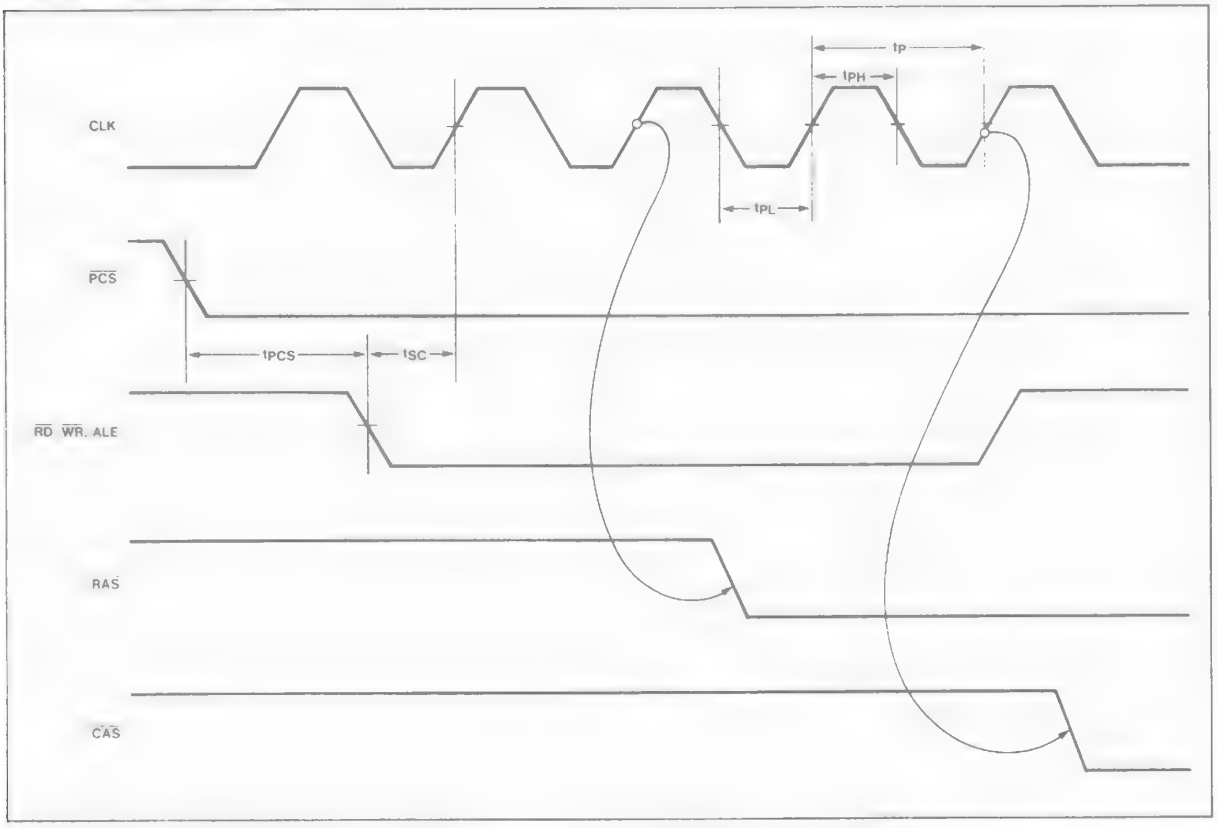


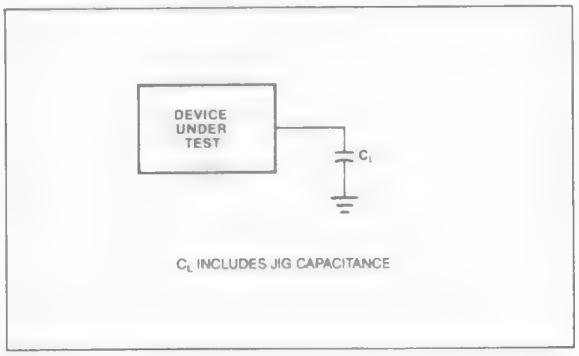
Table 2 8202A Output Test Loading.

Pin	Test Load
$\overline{SACK}$, $\overline{XACK}$	C_L = 30 pF
$\overline{OUT}_0$-$\overline{OUT}_6$	C_L = 160 pF
$\overline{RAS}_0$-$\overline{RAS}_3$	C_L = 60 pF
$\overline{WE}$	C_L = 224 pF
$\overline{CAS}$	C_L = 320 pF

NOTES:

1. t_{sc} is a reference point only. ALE, $\overline{RD}$, $\overline{WR}$, and REFRQ inputs do not have to be externally synchronized to 8202A clock.
2. If t_{RS} min and t_{MRS} min are met then, t_{CA}, t_{CR}, and t_{CC} are valid, otherwise t_{CS} is valid.
3. t_{ASR}, t_{RAH}, t_{ASC}, t_{CAH}, and t_{RSH} depend upon B0-B1 and CPU address remaining stable throughout the memory cycle. The address inputs are not latched by the 8202A.
4. For back-to-back refresh cycles, t_{RC} max = 13tp
5. t_{RC} max is valid only if t_{RMP} min is met (READ, WRITE followed by REFRESH) or t_{MRP} min is met (REFRESH followed by READ, WRITE)
6. t_{RFR} is valid only if t_{RS} min and t_{RMS} min are met.
7. t_{XW} min applies when $\overline{RD}$, $\overline{WR}$ has already gone high. Otherwise $\overline{XACK}$ follows $\overline{RD}$, $\overline{WR}$.
8. $\overline{WE}$ goes high according to t_{WCH} or t_{WW}, whichever occurs first.

A.C. TESTING LOAD CIRCUIT



9. t_{CA} applies only when in normal $\overline{SACK}$ mode
10. t_{CS} applies only when in delayed $\overline{SACK}$ mode.
11. t_{CHS} must be met only to ensure a $\overline{SACK}$ active pulse when in delayed $\overline{SACK}$ mode. $\overline{XACK}$ will always be activated for at least t_{XW} (t_P−25 nS). Violating t_{CHS} min does not otherwise affect device operation.

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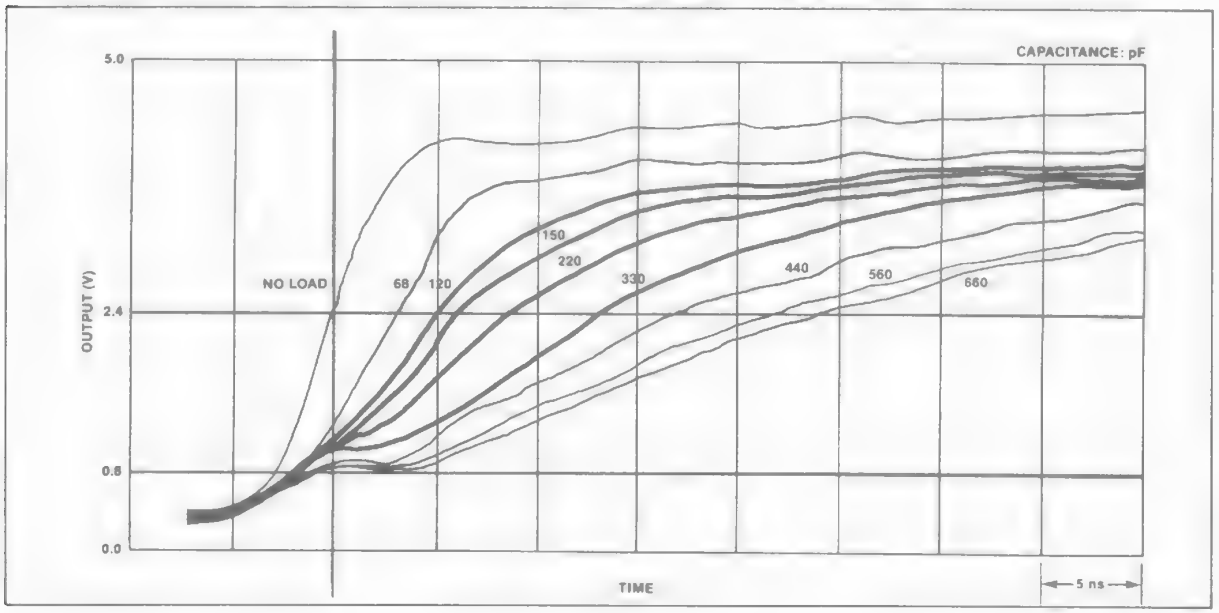
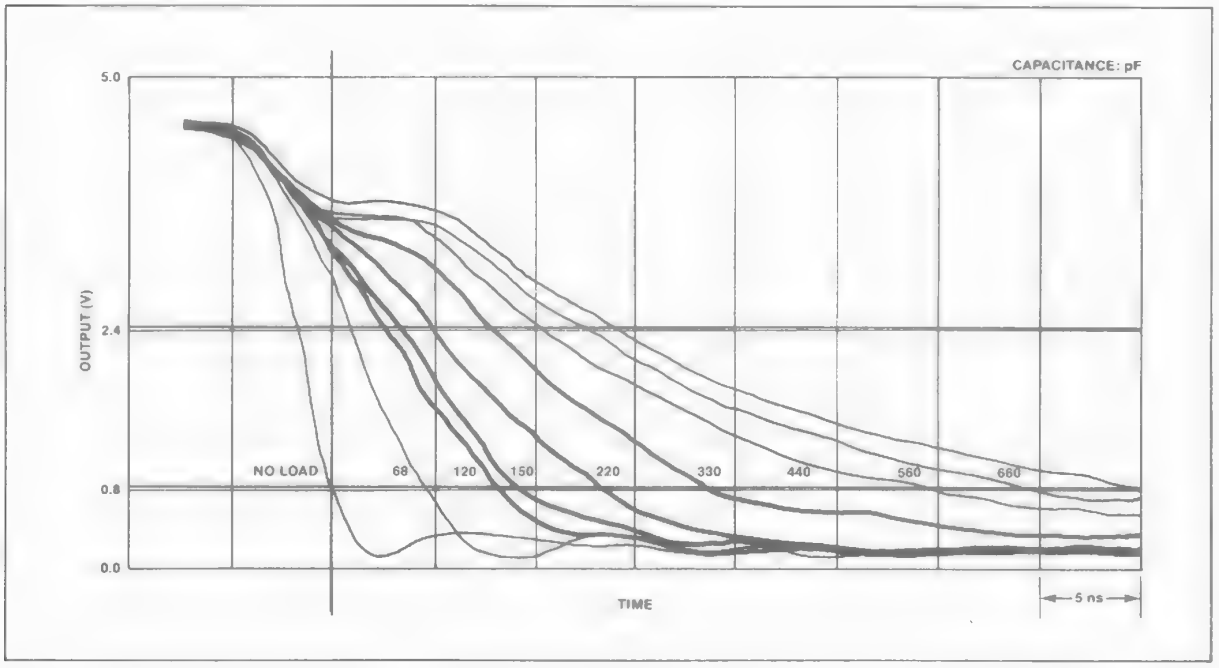
The typical rising and falling characteristic curves for the $\overline{OUT}$, $\overline{RAS}$, $\overline{CAS}$ and $\overline{WE}$ output buffers can be used to determine the effects of capacitive loading on the A.C. Timing Parameters. Using this design tool in conjunction with the timing waveforms, the designer can determine typical timing shifts based on system capacitive load.

A.C. CHARACTERISTICS FOR DIFFERENT CAPACITIVE LOADS





NOTE:

Use the Test Load as the base capacitance for estimating timing shifts for system critical timing parameters.

MEASUREMENT CONDITIONS:

$T_A = 25°C$
$V_{CC} = +5V$
$t_p = 50$ ns

Pins not measured are loaded with the Test Load capacitance.

Example: Find the effect on t_{CR} and t_{CC} using 64 2118 Dynamic RAMs configured in 4 banks.

1. Determine the typical RAS and CAS capacitance: From the data sheet RAS = 4 pF and CAS = 4 pF.
   ∴ RAS load = 64 pF + board capacitance.
   CAS load = 256 pF + board capacitance.
   Assume 2 pF/in (trace length) for board capacitance.
2. From the waveform diagrams, we determine that the falling edge timing is needed for t_{CR} and t_{CC}. Next find the curve that *best* approximates the test load; i.e., 68 pF for RAS and 330 pF for CAS.
3. If we use 72 pF for RAS loading, then the t_{CR} (max.) spec should be increased by *about* 1 ns. Similarly if we use 288 pF for CAS, then t_{CC} (min.) and (max.) should decrease about 1 ns.

PRELIMINARY

8203
64K DYNAMIC RAM CONTROLLER

- Provides All Signals Necessary to Control 64K (2164) and 16K (2117, 2118) Dynamic Memories
- Directly Addresses and Drives Up to 64 Devices Without External Drivers
- Provides Address Multiplexing and Strobes
- Provides a Refresh Timer and a Refresh Counter
- Provides Refresh/Access Arbitration
- Internal Clock Capability with the 8203-1 and the 8203-3
- Fully Compatible with Intel® 8080A, 8085A, iAPX 88, and iAPX 86 Family Microprocessors
- Provides System Acknowledge and Transfer Acknowledge Signals
- Refresh Cycles May be Internally or Externally Requested (For Transparent Refresh)
- Internal Series Damping Resistors on RAS, CAS and WE Outputs
- Available in EXPRESS —Standard Temperature Range

The Intel® 8203 is a Dynamic Ram System Controller designed to provide all signals necessary to use 2164, 2118 or 2117 Dynamic RAMs in microcomputer systems. The 8203 provides multiplexed addresses and address strobes, refresh logic, refresh/access arbitration. Refresh cycles can be started internally or externally. The 8203-1 and the 8203-3 support Advanced-Read mode and an internal crystal oscillator. The 8203-3 is a ±5% V_{CC} part.

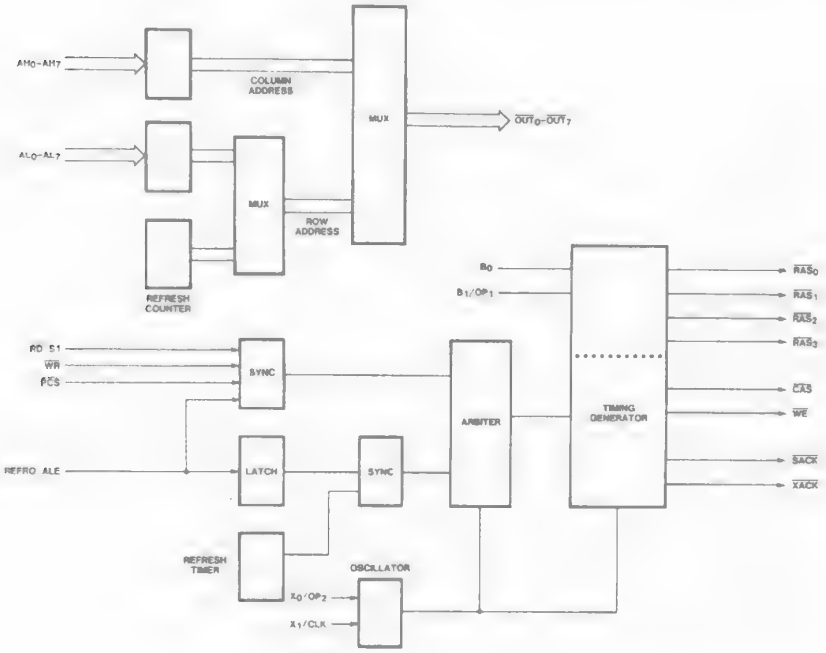


Figure 1. 8203 Block Diagram

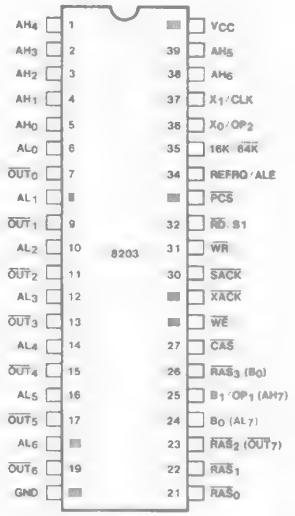


Figure 2. Pin Configuration

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JULY 1982
ORDER NUMBER: 21044-002

Table 1. Pin Descriptions

Symbol	Pin No.	Type	Name and Function
AL_0 AL_1 AL_2 AL_3 AL_4 AL_5 AL_6	6 [illegible] 10 12 14 16 18	I I I I I I I	**Address Low:** CPU address inputs used to generate memory row address.
AH_0 AH_1 AH_2 AH_3 AH_4 AH_5 AH_6	5 [illegible] 3 2 1 39 38	I I I I I I I	**Address High:** CPU address inputs used to generate memory column address.
B_0/AL_7 $B_1/OP_1/AH_7$	24 25	I I	**Bank Select Inputs:** Used to gate the appropriate RAS output for a memory cycle. B_1/OP_1 option used to select the Advanced Read Mode. (Not available in 64K mode.) See Figure 5. When in 64K RAM Mode, pins 24 and 25 operate as the AL_7 and AH_7 address inputs.
$\overline{PCS}$	33	I	**Protected Chip Select:** Used to enable the memory read and write inputs. Once a cycle is started, it will not abort even if $\overline{PCS}$ goes inactive before cycle completion.
$\overline{WR}$	31	I	**Memory Write Request.**
$\overline{RD}/S1$	32	I	**Memory Read Request:** S1 function used in Advanced Read mode selected by OP_1 (pin 25).
REFRQ/ALE	34	I	**External Refresh Request:** ALE function used in Advanced Read mode, selected by OP_1 (pin 25).
$\overline{OUT}_0$ $\overline{OUT}_1$ $\overline{OUT}_2$ $\overline{OUT}_3$ $\overline{OUT}_4$ $\overline{OUT}_5$ $\overline{OUT}_6$	7 9 11 13 15 17 19	O O O O O O O	**Output of the Multiplexer:** These outputs are designed to drive the addresses of the Dynamic RAM array. (Note that the $\overline{OUT}_{0-7}$ pins do not require inverters or drivers for proper operation.)
$\overline{WE}$	28	O	**Write Enable:** Drives the Write Enable inputs of the Dynamic RAM array.
$\overline{CAS}$	27	O	**Column Address Strobe:** This output is used to latch the Column Address into the Dynamic RAM array.
$\overline{RAS}_0$ $\overline{RAS}_1$ $\overline{RAS}_2/\overline{OUT}_7$ $\overline{RAS}_3/B_0$	21 22 23 26	O O O I/O	**Row Address Strobe:** Used to latch the Row Address into the bank of dynamic RAMs, selected by the 8203 Bank Select pins (B_0, B_1/OP_1). In 64K mode, only $\overline{RAS}_0$ and $\overline{RAS}_1$ are available; pin 23 operates as $\overline{OUT}_7$ and pin 26 operates as the B_0 bank select input.
$\overline{XACK}$	29	O	**Transfer Acknowledge:** This output is a strobe indicating valid data during a read cycle or data written during a write cycle. $\overline{XACK}$ can be used to latch valid data from the RAM array.
$\overline{SACK}$	30	O	**System Acknowledge:** This output indicates the beginning of a memory access cycle. It can be used as an advanced transfer acknowledge to eliminate wait states. (Note: If a memory access request is made during a refresh cycle, $\overline{SACK}$ is delayed until $\overline{XACK}$ in the memory access cycle).
X_0/OP_2 X_1/CLK	36 37	I/O I/O	**Oscillator Inputs:** These inputs are designed for a quartz crystal to control the frequency of the oscillator. If X_0/OP_2 is shorted to pin 40 (V_{CC}) or if X_0/OP_2 is connected to +12V through a 1KΩ resistor then X_1/CLK becomes a TTL input for an external clock. (Note: Crystal mode for the 8203-1 and the 8203-3 only).
$16K/\overline{64K}$	35	I	**Mode Select:** This input selects 16K mode (2117, 2118) or 64K mode (2164). Pins 23-26 change function based on the mode of operation.
V_{CC}	40		**Power Supply:** +5V.
GND	20		**Ground.**

Functional Description

The 8203 provides a complete dynamic RAM controller for microprocessor systems as well as expansion memory boards. All of the necessary control signals are provided for 2164, 2118 and 2117 dynamic RAMs.

The 8203 has two modes, one for 16K dynamic RAMs and one for 64Ks, controlled by pin 35.

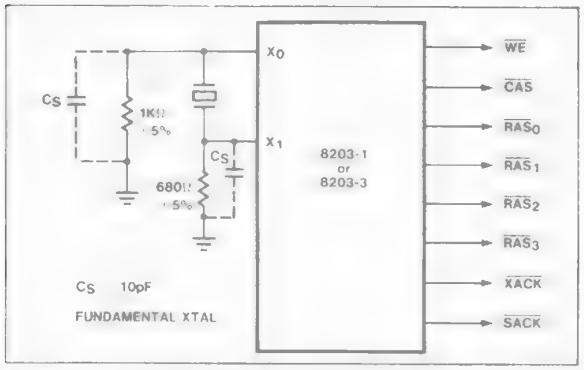


Figure 3. Crystal Operation for the 8203-1 and 8203-3

All 8203 timing is generated from a single reference clock. This clock is provided via an external oscillator or an on-chip crystal oscillator. All output signal transitions are synchronous with respect to this clock reference, except for the trailing edges of the CPU handshake signals $\overline{SACK}$ and $\overline{XACK}$.

CPU memory requests normally use the $\overline{RD}$ and $\overline{WR}$ inputs. The Advanced-Read mode allows ALE and S1 to be used in place of the $\overline{RD}$ input.

Failsafe refresh is provided via an internal timer which generates refresh requests. Refresh requests can also be generated via the REFRQ input.

An on-chip synchronizer/arbiter prevents memory and refresh requests from affecting a cycle in progress. The READ, WRITE, and external REFRESH requests may be asynchronous to the 8203 clock; on-chip logic will synchronize the requests, and the arbiter will decide if the requests should be delayed, pending completion of a cycle in progress.

16K/$\overline{64K}$ Option Selection

Pin 35 is a strap input that controls the two 8203 modes. Figure 4 shows the four pins that are multiplexed. In 16K mode (pin 35 tied to V_{CC} or left open), the 8203 has two Bank Select inputs to select one of four $\overline{RAS}$ outputs. In this mode, the 8203 is exactly compatible with the Intel 8202A Dynamic RAM Controller. In 64K mode (pin 35 tied to GND), there is only one Bank Select input (pin 26) to select the two $\overline{RAS}$ outputs. More than two banks of 64K dynamic RAM's can be used with external logic.

Other Option Selections

The 8203 has three strapping options. When OP_1 is selected (16K mode only), pin 32 changes from a $\overline{RD}$ input to an S1 input, and pin 34 changes from a REFRQ input to an ALE input. See "Refresh Cycles" and "Read Cycles" for more detail. OP_1 is selected by tying pin 25 to +12V through a 5.1K ohm resistor on the 8203-1 or 8203-3 only.

When OP_2 is selected, the internal oscillator is disabled and pin 37 changes from a crystal input (X_1) to a CLK input for an external TTL clock. OP_2 is selected by shorting pin 36 (X_0/OP_2) directly to pin 40 (V_{CC}). No current limiting resistor should be used. OP_2 may also be selected by tying pin 36 to +12V through a 1KΩ resistor.

Refresh Timer

The refresh timer is used to monitor the time since the last refresh cycle occurred. When the appropriate amount of time has elapsed, the refresh timer will request a refresh cycle. External refresh requests will reset the refresh timer.

Refresh Counter

The refresh counter is used to sequentially refresh all of the memory's rows. The 8-bit counter is incremented after every refresh cycle.

Pin #	16K Function	64K Function
23	$\overline{RAS_2}$	Address Output ($\overline{OUT_7}$)
24	Bank Select (B_0)	Address Input (AL_7)
25	Bank Select (B_1)	Address Input (AH_7)
26	$\overline{RAS_3}$	Bank Select (B_0)

Figure 4. 16K/$\overline{64K}$ Mode Selection

	Inputs		Outputs			
	B_1	B_0	$\overline{RAS_0}$	$\overline{RAS_1}$	$\overline{RAS_2}$	$\overline{RAS_3}$
16K Mode	0	0	0	1	1	1
	0	1	1	0	1	1
	1	0	1	1	0	1
	1	1	1	1	1	0
64K Mode	—	0	0	1	—	—
	—	1	1	0	—	—

Figure 5. Bank Selection

Description	Pin #	Normal Function	Option Function
B_1/OP_1 (16K only)/AH_7	25	Bank (RAS) Select	Advanced-Read Mode (see text)
X_0 OP_2	36	Crystal Oscillator (8203-1 and 8203-3)	External Oscillator

Figure 6. 8203 Option Selection

Address Multiplexer

The address multiplexer takes the address inputs and the refresh counter outputs, and gates them onto the address outputs at the appropriate time. The address outputs, in conjunction with the $\overline{RAS}$ and $\overline{CAS}$ outputs, determine the address used by the dynamic RAMs for read, write, and refresh cycles. During the first part of a read or write cycle, AL_0–AL_7 are gated to $\overline{OUT}_0$–$\overline{OUT}_7$, then AH_0–AH_7 are gated to the address outputs.

During a refresh cycle, the refresh counter is gated onto the address outputs. All refresh cycles are RAS-only refresh ($\overline{CAS}$ inactive, $\overline{RAS}$ active).

To minimize buffer delay, the information on the address outputs is inverted from that on the address inputs.

$\overline{OUT}_0$–$\overline{OUT}_7$ do not need inverters or buffers unless additional drive is required.

Synchronizer/Arbiter

The 8203 has three inputs, REFRQ/ALE (pin 34), $\overline{RD}$ (pin 32) and $\overline{WR}$ (pin 31). The $\overline{RD}$ and $\overline{WR}$ inputs allow an external CPU to request a memory read or write cycle, respectively. The REFRQ/ALE input allows refresh requests to be requested external to the 8203.

All three of these inputs may be asynchronous with respect to the 8203's clock. The arbiter will resolve conflicts between refresh and memory requests, for both pending cycles and cycles in progress. Read and write requests will be given priority over refresh requests.

System Operation

The 8203 is always in one of the following states:

a) IDLE
b) TEST Cycle
c) REFRESH Cycle
d) READ Cycle
e) WRITE Cycle

The 8203 is normally in the IDLE state. Whenever one of the other cycles is requested, the 8203 will leave the IDLE state to perform the desired cycle. If no other cycles are pending, the 8203 will return to the IDLE state.

Test Cycle

The TEST Cycle is used to check operation of several 8203 internal functions. TEST cycles are requested by activating the $\overline{PCS}$, $\overline{RD}$ and $\overline{WR}$ inputs. The TEST Cycle will reset the refresh address counter and perform a WRITE Cycle. The TEST Cycle should not be used in normal system operation, since it would affect the dynamic RAM refresh.

Refresh Cycles

The 8203 has two ways of providing dynamic RAM refresh:

1) Internal (failsafe) refresh
2) External (hidden) refresh

Both types of 8203 refresh cycles activate all of the $\overline{RAS}$ outputs, while CAS, WE, $\overline{SACK}$, and $\overline{XACK}$ remain inactive.

Internal refresh is generated by the on-chip refresh timer. The timer uses the 8203 clock to ensure that refresh of all rows of the dynamic RAM occurs every 2 milliseconds (128 cycles) or every 4 milliseconds (256 cycles). If REFRQ is inactive, the refresh timer will request a refresh cycle every 10-16 microseconds.

External refresh is requested via the REFRQ input (pin 34). External refresh control is not available when the Advanced-Read mode is selected. External refresh requests are latched, then synchronized to the 8203 clock.

The arbiter will allow the refresh request to start a refresh cycle only if the 8203 is not in the middle of a cycle.

When the 8203 is in the idle state a simultaneous memory request and external refresh request will result in the memory request being honored first. This 8203 characteristic can be used to "hide" refresh cycles during system operation. A circuit similar to Figure 7 can be used to decode the CPU's instruction fetch status to generate an external refresh request. The refresh request is latched while the 8203 performs the instruction fetch; the refresh cycle will start immediately after the memory cycle is completed, even if the RD input has not gone inactive. If the CPU's instruction decode time is long enough, the 8203 can complete the refresh cycle before the next memory request is generated.

If the 8203 is not in the idle state then a simultaneous memory request and an external refresh request may result in the refresh request being honored first.

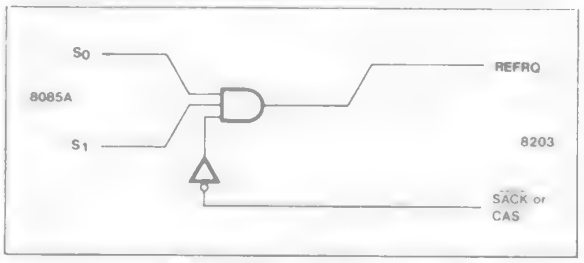


Figure 7. Hidden Refresh

Certain system configurations require complete external refresh requests. If external refresh is requested faster than the minimum internal refresh timer (t_{REF}), then, in effect, all refresh cycles will be caused by the external refresh request, and the internal refresh timer will never generate a refresh request.

Read Cycles

The 8203 can accept two different types of memory Read requests:

1) Normal Read, via the $\overline{RD}$ input
2) Advanced Read, using the S1 and ALE inputs (16K mode only)

The user can select the desired Read request configuration via the B1/OP1 hardware strapping option on pin 25.

	Normal Read	Advanced Read
Pin 25	B1 input	OP_1 (+12V)
Pin 32	RD input	S1 input
Pin 34	REFRQ input	ALE input
# RAM banks	4 ($\overline{RAS}_{0-3}$)	2 ($\overline{RAS}_{2-3}$)
Ext. Refresh	Yes	No

Figure 8. 8203 Read Options

Normal Reads are requested by activating the $\overline{RD}$ input, and keeping it active until the 8203 responds with an $\overline{XACK}$ pulse. The $\overline{RD}$ input can go inactive as soon as the command hold time (t_{CHS}) is met.

Advanced Read cycles are requested by pulsing ALE while S1 is active; if S1 is inactive (low) ALE is ignored. Advanced Read timing is similiar to Normal Read timing, except the falling edge of ALE is used as the cycle start reference.

If a Read cycle is requested while a refresh cycle is in progress, then the 8203 will set the internal delayed-SACK latch. When the Read cycle is eventually started, the 8203 will delay the active $\overline{SACK}$ transition until $\overline{XACK}$ goes active, as shown in the AC timing diagrams. This delay was designed to compensate for the CPU's READY setup and hold times. The delayed–SACK latch is cleared after every READ cycle.

Based on system requirements, either $\overline{SACK}$ or $\overline{XACK}$ can be used to generate the CPU READY signal. $\overline{XACK}$ will normally be used; if the CPU can tolerate an advanced READY, then $\overline{SACK}$ can be used, but only if the CPU can tolerate the amount of advance provided by $\overline{SACK}$. If $\overline{SACK}$ arrives too early to provide the appropriate number of WAIT states, then either $\overline{XACK}$ or a delayed form of $\overline{SACK}$ should be used.

Write Cycles

Write cycles are similiar to Normal Read cycles, except for the $\overline{WE}$ output. $\overline{WE}$ is held inactive for Read cycles, but goes active for Write cycles. All 8203 Write cycles are "early-write" cycles; $\overline{WE}$ goes active before $\overline{CAS}$ goes active by an amount of time sufficient to keep the dynamic RAM output buffers turned off.

General System Considerations

All memory requests (Normal Reads, Advanced Reads, Writes) are qualified by the $\overline{PCS}$ input. $\overline{PCS}$ should be stable, either active or inactive, prior to the leading edge of $\overline{RD}$, $\overline{WR}$, or ALE. Systems which use battery backup should pullup $\overline{PCS}$ to prevent erroneous memory requests.

In order to minimize propagation delay, the 8203 uses an inverting address multiplexer without latches. The system must provide adequate address setup and hold times to guarantee $\overline{RAS}$ and $\overline{CAS}$ setup and hold times for the RAM. The t_{AD} AC parameter should be used for this system calculation.

The B_0-B_1 inputs are similiar to the address inputs in that they are not latched. B_0 and B_1 should not be changed during a memory cycle, since they directly control which $\overline{RAS}$ output is activated.

The 8203 uses a two-stage synchronizer for the memory request inputs ($\overline{RD}$, $\overline{WR}$, ALE), and a separate two stage synchronizer for the external refresh input (REFRQ). As with any synchronizer, there is always a finite probability of metastable states inducing system errors. The 8203 synchronizer was designed to have a system error rate less than 1 memory cycle every three years based on the full operating range of the 8203.

A microprocessor system is concerned when the data is valid after $\overline{RD}$ goes low. See Figure 9. In order to calculate memory read access times, the dynamic RAM's A.C. specifications must be examined, especially the RAS-access time (t_{RAC}) and the CAS-access time (t_{CAC}). Most configurations will be CAS-access limited; i.e., the data from the RAM will be stable $t_{cc,max}$ (8203) + t_{CAC} (RAM) after a memory read cycle is started. Be sure to add any delays (due to buffers, data latches, etc.) to calculate the overall read access time.

Since the 8203 normally performs "early-write" cycles, the data must be stable at the RAM data inputs by the time $\overline{CAS}$ goes active, including the RAM's data setup time. If the system does not normally guarantee sufficient write data setup, you must either delay the $\overline{WR}$ input signal or delay the 8203 $\overline{WE}$ output.

Delaying the $\overline{WR}$ input will delay all 8203 timing, including the READY handshake signals, $\overline{SACK}$ and $\overline{XACK}$, which

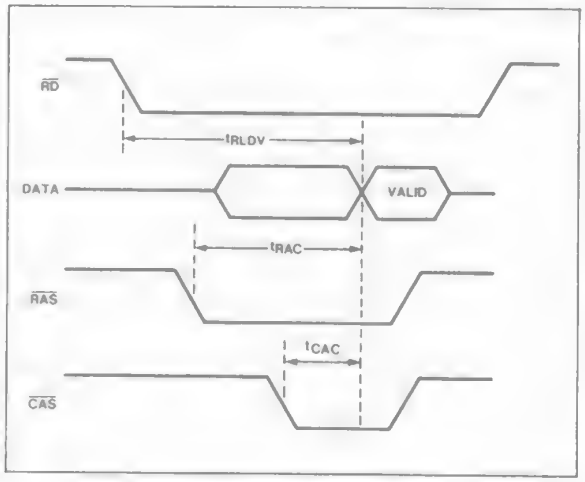


Figure 9. Read Access Time

may increase the number of WAIT states generated by the CPU.

If the $\overline{WE}$ output is externally delayed beyond the $\overline{CAS}$ active transition, then the RAM will use the falling edge of $\overline{WE}$ to strobe the write data into the RAM. This $\overline{WE}$ transition should not occur too late during the CAS active transition, or else the $\overline{WE}$ to $\overline{CAS}$ requirements of the RAM will not be met.

The $\overline{RAS}_{0-3}$, $\overline{CAS}$, $\overline{OUT}_{0-7}$, and $\overline{WE}$ outputs contain on-chip series damping resistors (typically 20Ω) to minimize overshoot.

Some dynamic RAMs require more than 2.4V V_{IH}. Noise immunity may be improved for these RAMs by adding pull-up resistors to the 8203's outputs. Intel RAMs do not require pull-up resistors.

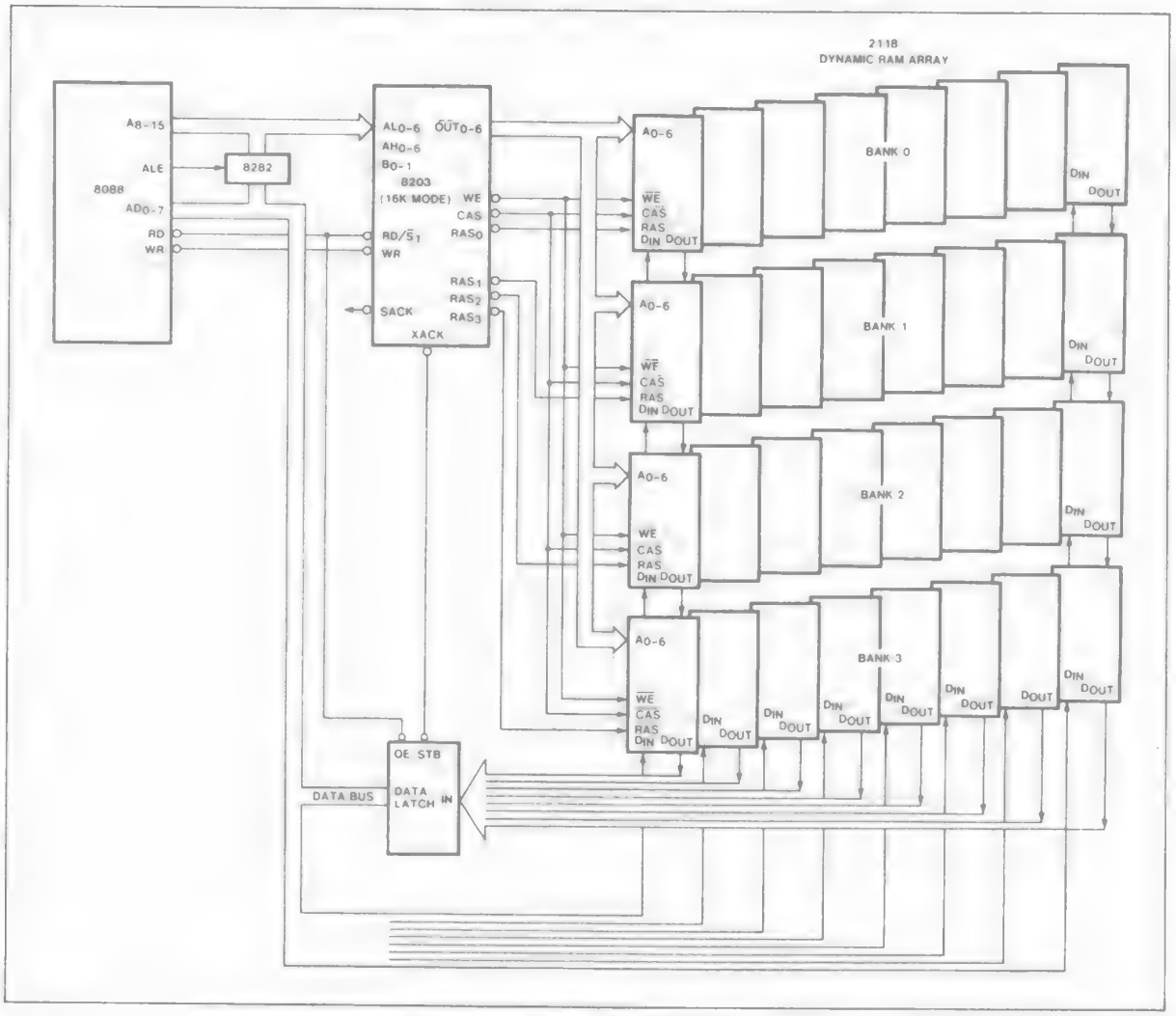


Figure 10. Typical 8088 System

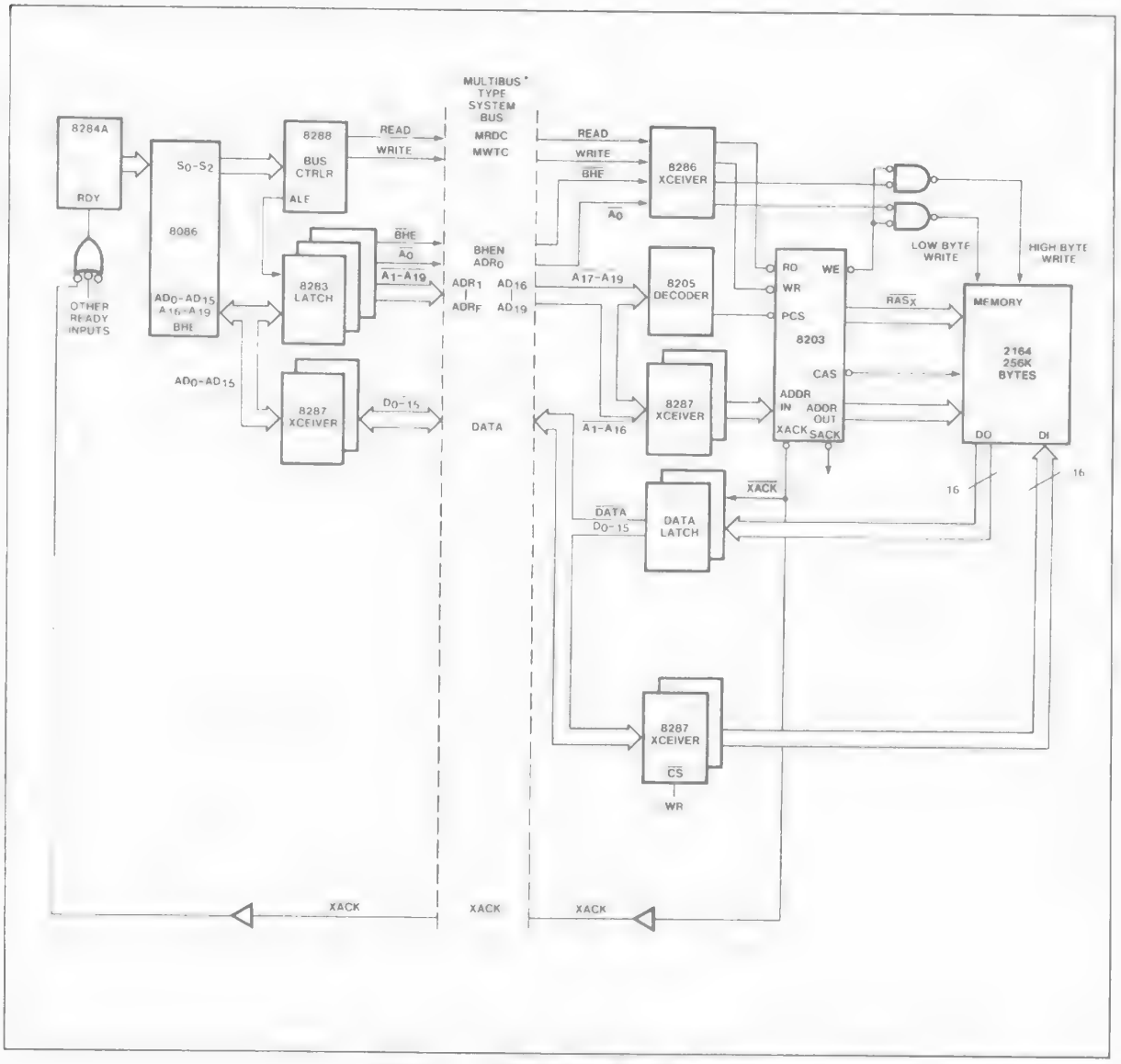


Figure 11. 8086/256K Byte System

ABSOLUTE MAXIMUM RATINGS*

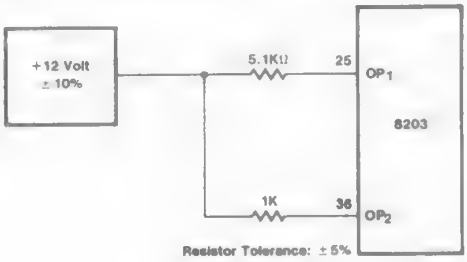
Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage On any Pin
With Respect to Ground ..... −0.5V to +7V[4]
Power Dissipation ..... 1.6 Watts

**NOTE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS T_A = 0°C to 70°C; V_{CC} = 5.0V ± 10% (5.0V ± 5% for 8203-3); GND = 0V

Symbol	Parameter	Min	Max	Units	Test Conditions
V_C	Input Clamp Voltage		−1.0	V	I_C = −5 mA
I_{CC}	Power Supply Current		290	mA	
I_F	Forward Input Current CLK, 64K/16K Mode select All Other Inputs[3]		 −2.0 −320	 mA μA	 V_F = 0.45V V_F = 0.45V
I_R	Reverse Input Current[3]		40	μA	V_R = V_{CC}; Note 1
V_{OL}	Output Low Voltage $\overline{SACK}$, $\overline{XACK}$ All Other Outputs		 0.45 0.45	 V V	 I_{OL} = 5 mA I_{OL} = 3 mA
V_{OH}	Output High Voltage $\overline{SACK}$, $\overline{XACK}$ All Other Outputs	 2.4 2.6		 V V	V_{IL} = 0.65 V I_{OH} = −1 mA I_{OH} = −1 mA
V_{IL}	Input Low Voltage		0.8	V	V_{CC} = 5.0V (Note 2)
V_{IH1}	Input High Voltage	2.0	V_{CC}	V	V_{CC} = 5.0V
V_{IH2}	Option Voltage		V_{CC}	V	(Note 4)
C_{IN}	Input Capacitance		30	pF	F = 1 MHz V_{BIAS} = 2.5V, V_{CC} = 5V T_A = 25°C

NOTES:
1. I_R = 200 μA for pin 37 (CLK).
2. For test mode $\overline{RD}$ & $\overline{WR}$ must be held at GND.
3. Except for pin 36 in XTAL mode.
4.



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A.C. CHARACTERISTICS

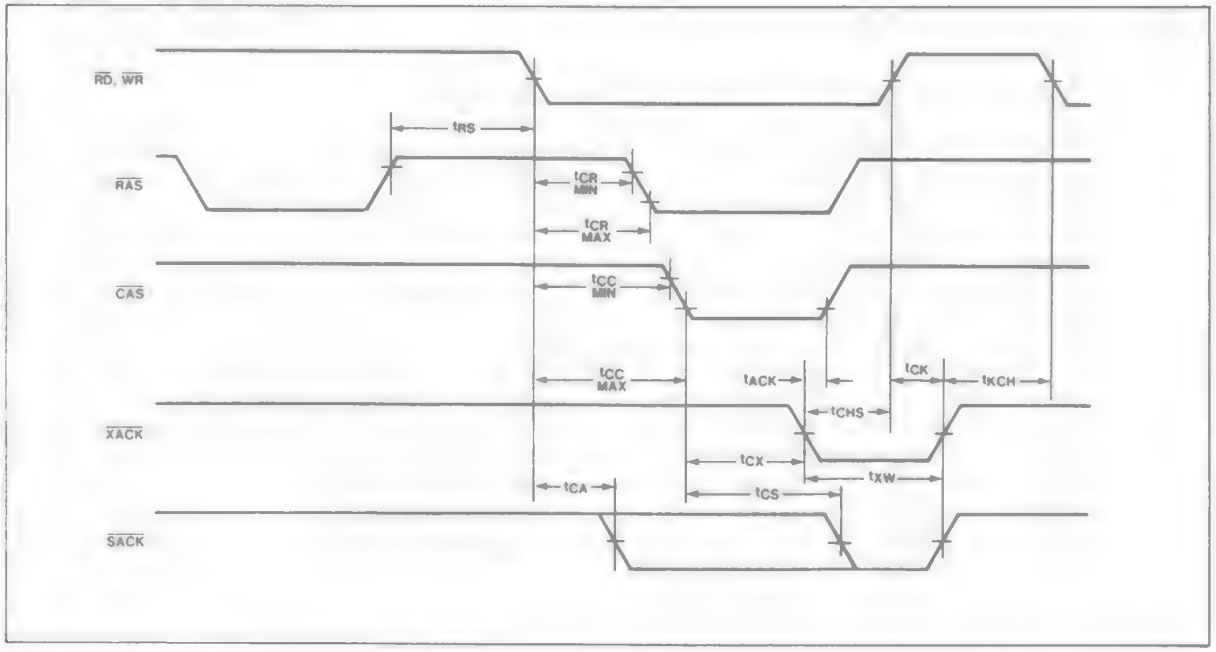
T_J = 0°C to 70°C; V_{CC} = 5V ± 10% (5.0V ± 5% for 8203-3); GND = 0V

Measurements made with respect to $\overline{RAS}_0$-$\overline{RAS}_3$, $\overline{CAS}$, $\overline{WE}$, $\overline{OUT}_0$-$\overline{OUT}_6$ are at 2.4V and 0.8V. All other pins are measured at 1.5V. All times are in nsec.

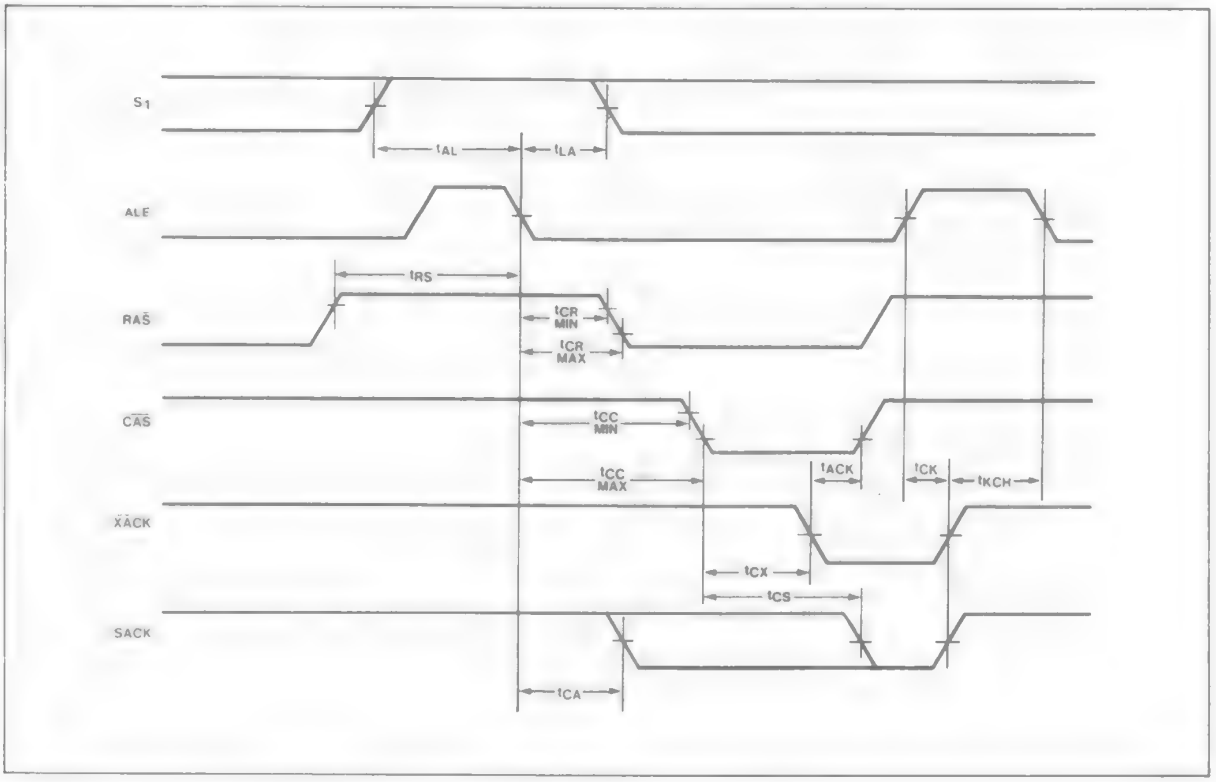
Symbol	Parameter	Min	Max	Notes
t_P	Clock Period	40	54	
t_{PH}	External Clock High Time	20		
t_{PL}	External Clock Low Time—above (>) 20 mHz	17		
t_{PL}	External Clock Low Time—below (≤) 20 mHz	20		
t_{RC}	Memory Cycle Time	10tp − 30	12tp	4, 5
t_{REF}	Refresh Time (128 cycles)	264tp	288tp	
t_{RP}	$\overline{RAS}$ Precharge Time	4tp − 30		
t_{RSH}	$\overline{RAS}$ Hold After $\overline{CAS}$	5tp − 30		3
t_{ASR}	Address Setup to $\overline{RAS}$	tp − 30		3
t_{RAH}	Address Hold From $\overline{RAS}$	tp − 10		3
t_{ASC}	Address Setup to $\overline{CAS}$	tp − 30		3
t_{CAH}	Address Hold from $\overline{CAS}$	5tp − 20		3
t_{CAS}	$\overline{CAS}$ Pulse Width	5tp − 10		
t_{WCS}	$\overline{WE}$ Setup to $\overline{CAS}$	tp − 40		
t_{WCH}	$\overline{WE}$ Hold After $\overline{CAS}$	5tp − 35		8
t_{RS}	$\overline{RD}$, $\overline{WR}$, ALE, REFRQ delay from $\overline{RAS}$	5tp		2, 6
t_{MRP}	$\overline{RD}$, $\overline{WR}$ setup to $\overline{RAS}$	0		5
t_{RMS}	REFRQ setup to $\overline{RD}$, $\overline{WR}$	2tp		6
t_{RMP}	REFRQ setup to $\overline{RAS}$	2tp		5
t_{PCS}	$\overline{PCS}$ Setup to $\overline{RD}$, $\overline{WR}$, ALE	20		
t_{AL}	S1 Setup to ALE	15		
t_{LA}	S1 Hold from ALE	30		
t_{CR}	$\overline{RD}$, $\overline{WR}$, ALE to $\overline{RAS}$ Delay	tp + 30	2tp + 70	2
t_{CC}	$\overline{RD}$, $\overline{WR}$, ALE to $\overline{CAS}$ Delay	3tp + 25	4tp + 85	2
t_{SC}	CMD Setup to Clock	15		1
t_{MRS}	$\overline{RD}$, $\overline{WR}$ setup to REFRQ	5		2
t_{CA}	$\overline{RD}$, $\overline{WR}$, ALE to $\overline{SACK}$ Delay		2tp + 47	2, 9
t_{CX}	$\overline{CAS}$ to $\overline{XACK}$ Delay	5tp − 25	5tp + 20	
t_{CS}	$\overline{CAS}$ to $\overline{SACK}$ Delay	5tp − 25	5tp + 40	2, 10
t_{ACK}	$\overline{XACK}$ to $\overline{CAS}$ Setup	10		
t_{XW}	$\overline{XACK}$ Pulse Width	tp − 25		7
t_{CK}	$\overline{SACK}$, $\overline{XACK}$ turn-off Delay		35	
t_{KCH}	CMD Inactive Hold after $\overline{SACK}$, $\overline{XACK}$	10		
t_{LL}	REFRQ Pulse Width	20		
t_{CHS}	CMD Hold Time	30		11
t_{RFR}	REFRQ to $\overline{RAS}$ Delay		4tp + 100	6
t_{WW}	$\overline{WR}$ to $\overline{WE}$ Delay	0	50	8
t_{AD}	CPU Address Delay	0	40	3

WAVEFORMS

Normal Read or Write Cycle



Advanced Read Mode



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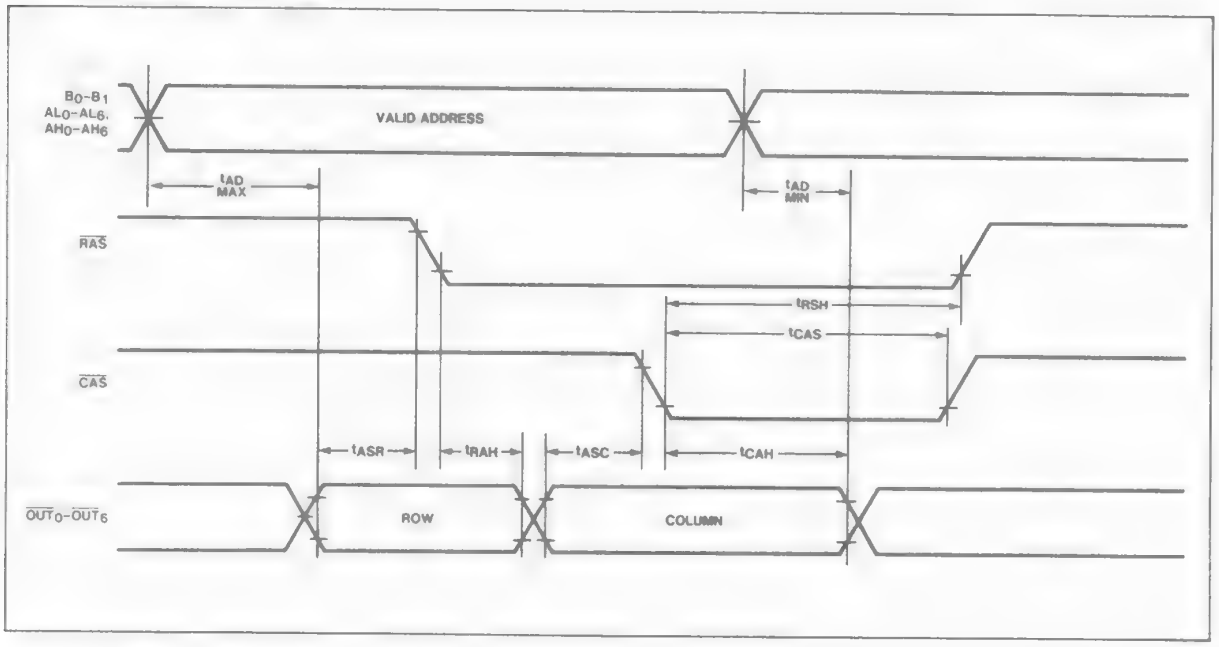
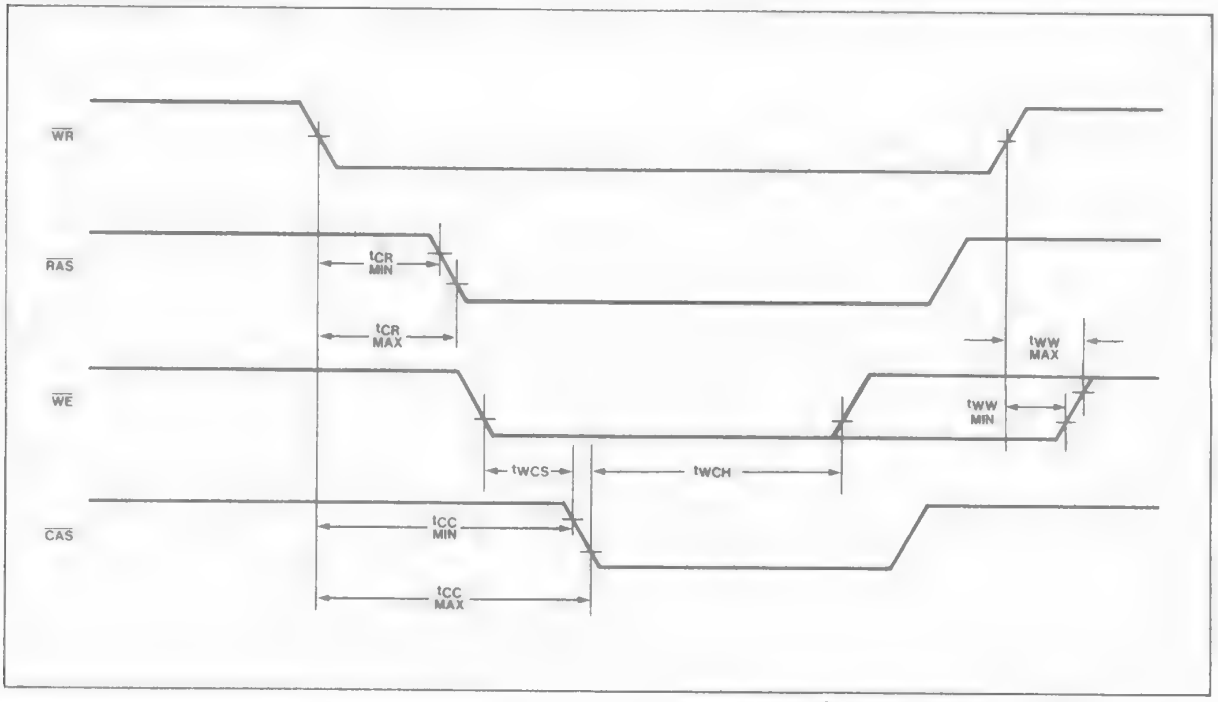
WAVEFORMS (cont'd)

Memory Compatibility Timing



Write Cycle Timing



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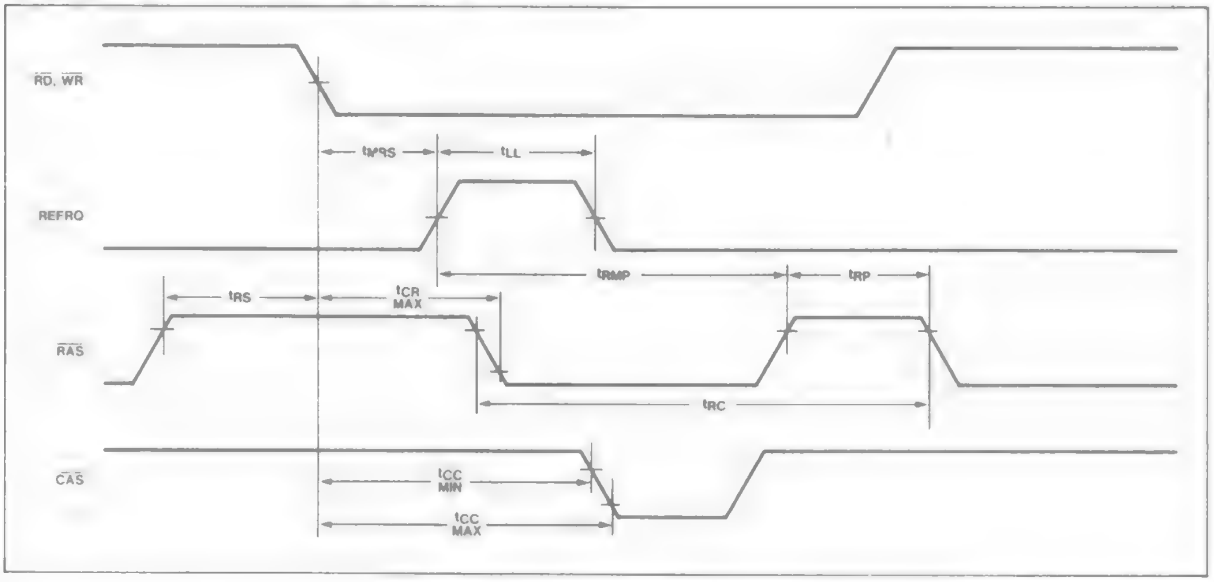
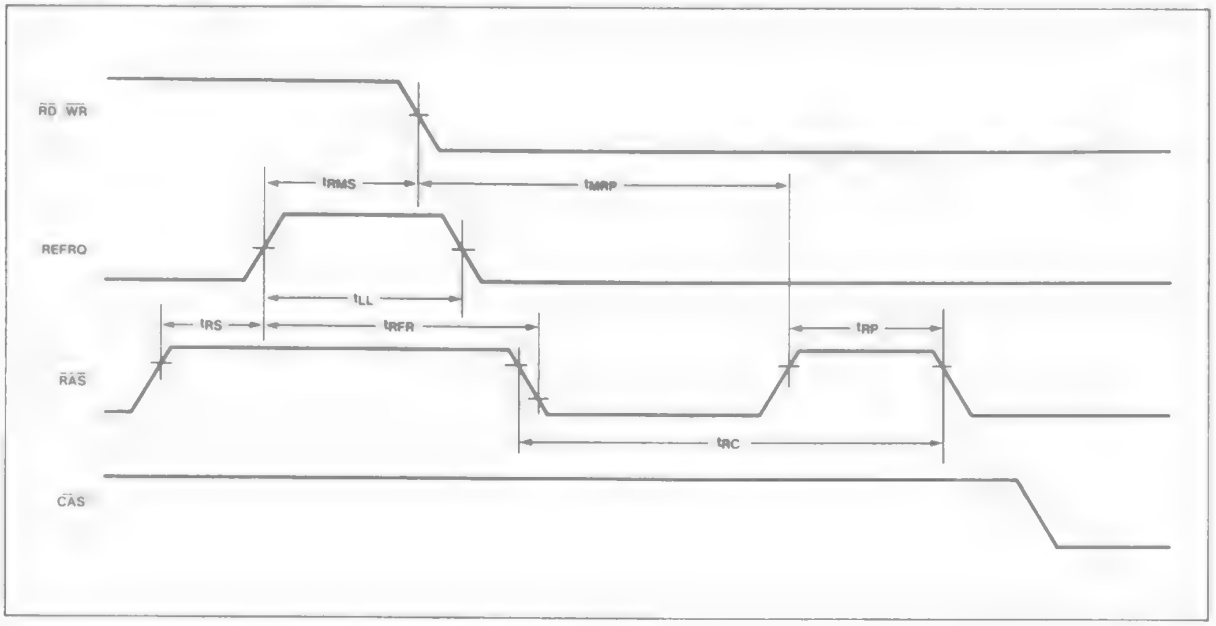
WAVEFORMS (cont'd)

Read or Write Followed By External Refresh



External Refresh Followed By Read or Write



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WAVEFORMS (cont'd)

Clock And System Timing

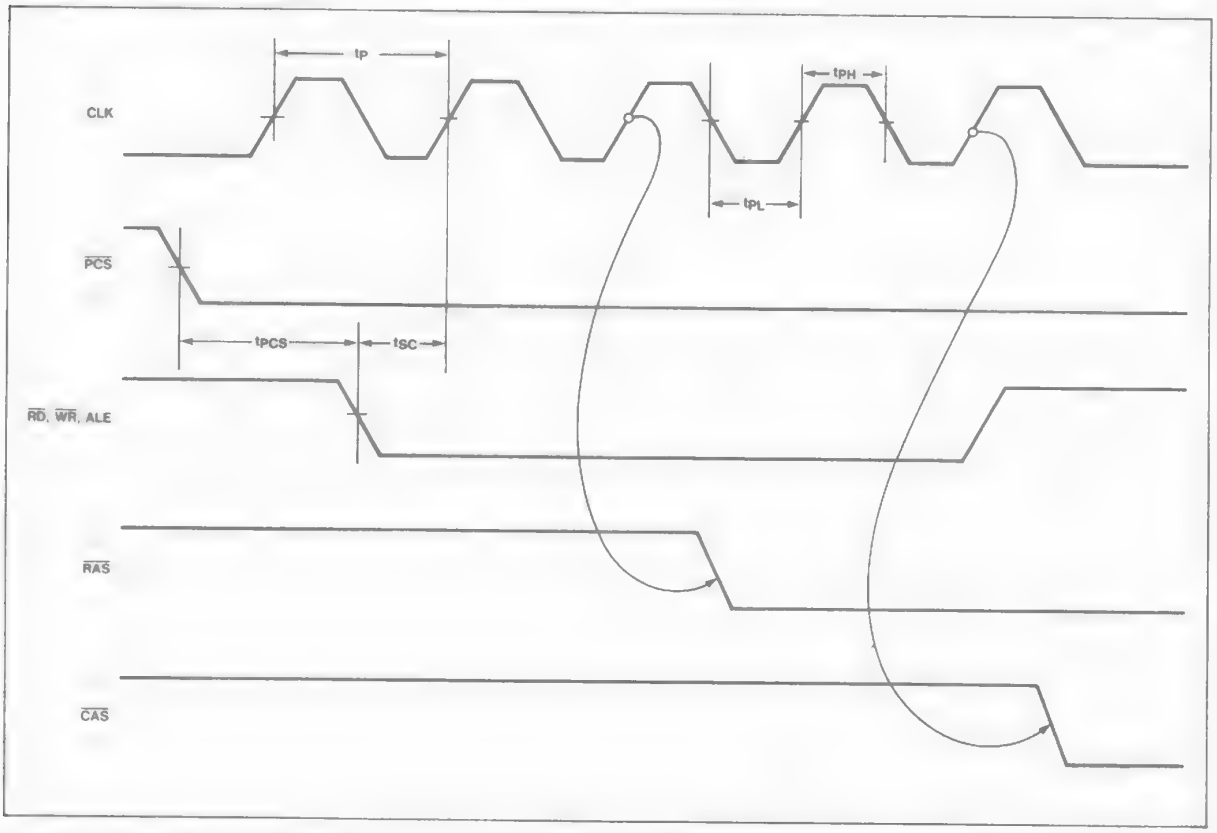


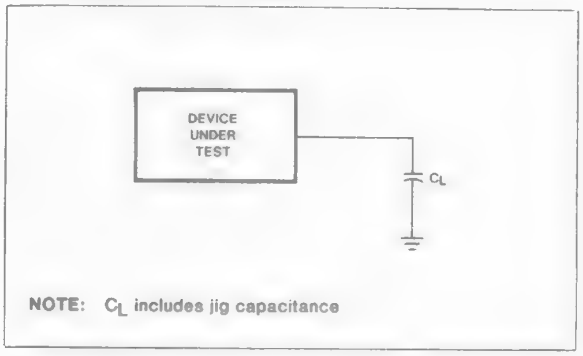
Table 2. 8203 Output Loading. All specifications are for the Test Load unless otherwise noted.

Pin	Test Load
$\overline{SACK}$, $\overline{XACK}$	C_L = 30 pF
$\overline{OUT}_0$-$\overline{OUT}_6$	C_L = 160 pF
$\overline{RAS}_0$-$\overline{RAS}_3$	C_L = 60 pF
$\overline{WE}$	C_L = 224 pF
$\overline{CAS}$	C_L = 320 pF

NOTES:

1. t_{SC} is a reference point only. ALE, $\overline{RD}$, $\overline{WR}$, and REFRQ inputs do not have to be externally synchronized to 8203 clock.
2. If t_{RS} min and t_{MRS} min are met then t_{CA}, t_{CR}, and t_{CC} are valid, otherwise t_{CS} is valid.
3. t_{ASR}, t_{RAH}, t_{ASC}, t_{CAH}, and t_{RSH} depend upon B0-B1 and CPU address remaining stable throughout the memory cycle. The address inputs are not latched by the 8203.
4. For back-to-back refresh cycles, t_{RC} max = 13tp
5. t_{RC} max is valid only if t_{RMP} min is met (READ, WRITE followed by REFRESH) or t_{MRP} min is met (REFRESH followed by READ, WRITE).
6. t_{RFR} is valid only if t_{RS} min and t_{RMS} min are met.
7. t_{XW} min applies when $\overline{RD}$, $\overline{WR}$ has already gone high. Otherwise $\overline{XACK}$ follows $\overline{RD}$, $\overline{WR}$.
8. $\overline{WE}$ goes high according to t_{WCH} or t_{WW}, whichever occurs first.

A.C. TESTING LOAD CIRCUIT

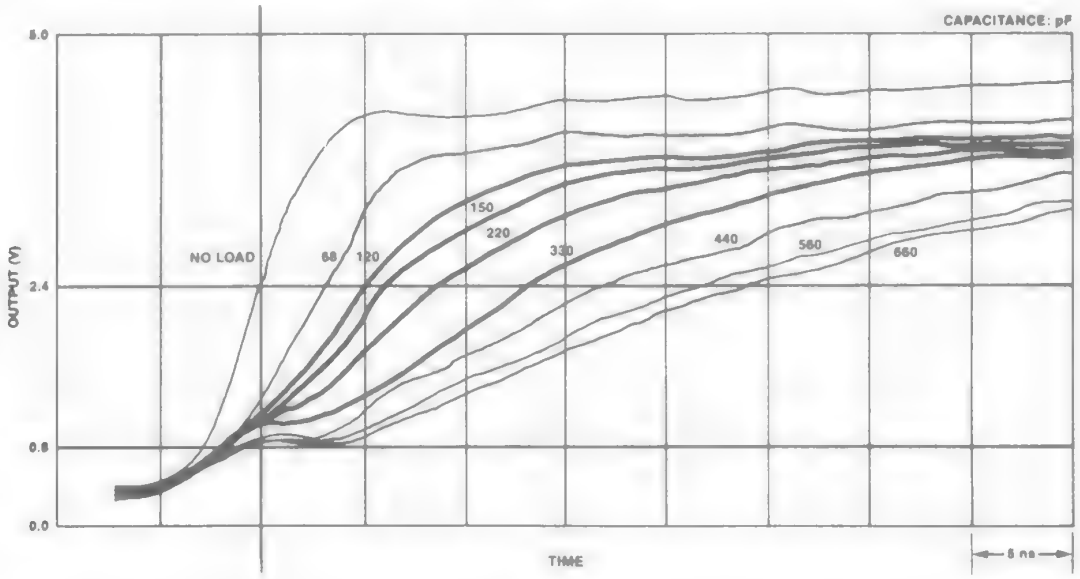


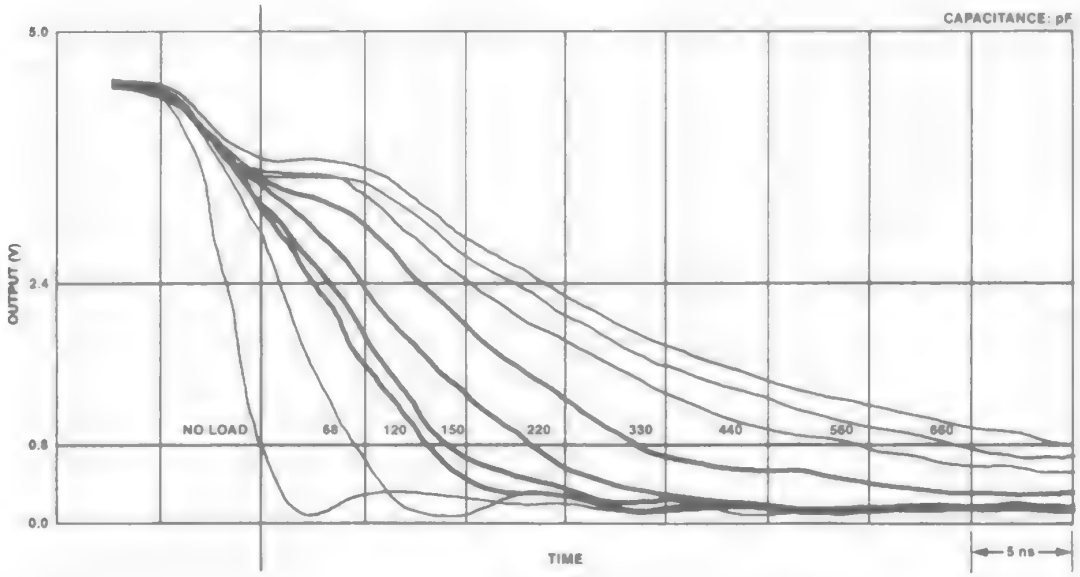
NOTE: C_L includes jig capacitance

9. t_{CA} applies only when in normal $\overline{SACK}$ mode.de.
10. t_{CS} applies only when in delayed $\overline{SACK}$ mode.
11. t_{CHS} must be be met only to ensure a $\overline{SACK}$ active pulse when in delayed $\overline{SACK}$ mode. $\overline{XACK}$ will always be activated for at least t_{XW} (t_P−25 nS). Violating t_{CHS} min does not otherwise affect device operation.

The typical rising and falling characteristic curves for the $\overline{OUT}$, $\overline{RAS}$, $\overline{CAS}$ and $\overline{WE}$ output buffers can be used to determine the effects of capacitive loading on the A.C. Timing Parameters. Using this design tool in conjunction with the timing waveforms, the designer can determine typical timing shifts based on system capacitive load.

A.C. CHARACTERISTICS FOR DIFFERENT CAPACITIVE LOADS





NOTE:
Use the Test Load as the base capacitance for estimating timing shifts for system critical timing parameters.

MEASUREMENT CONDITIONS:

$T_A = 25°C$
$V_{CC} = +5V$
$t_p = 50$ ns

Pins not measured are loaded with the Test Load capacitance

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Example: Find the effect on t_{CR} and t_{CC} using 32 2164 Dynamic RAMs configured in 2 banks.

1. Determine the typical RAS and CAS capacitance:
   From the data sheet RAS = 5 pF and CAS = 5 pF.
   ∴ RAS load = 80 pF + board capacitance.
   CAS load = 160 pF + board capacitance.
   Assume 2 pF/in (trace length) for board capacitance and for this example 4 inches for RAS and 8 inches for CAS.

2. From the waveform diagrams, we determine that the falling edge timing is needed for t_{CR} and t_{CC}. Next find the curve that *best* approximates the test load; i.e., 68 pF for RAS and 330 pF for CAS.

3. If we use 88 pF for RAS loading, then t_{CR} (min.) spec should be increased by about 1 ns, and t_{CR} (max.) spec should be increased by *about* 2 ns. Similarly if we use 176 pF for CAS, then t_{CC} (min.) should decrease by 3 ns and t_{CC} (max.) should decrease by about 7 ns.

PRELIMINARY

8206
ERROR DETECTION AND CORRECTION UNIT

- Detects and Corrects All Single Bit Errors
- Detects All Double Bit and Most Multiple Bit Errors
- 52 ns Maximum for Detection; 67 ns Maximum for Correction (16 Bit System)
- Expandable to Handle 80 Bit Memories
- Syndrome Outputs for Error Logging
- Separate Input and Output Busses—No Timing Strobes Required
- Supports Reads With and Without Correction, Writes, Partial (Byte) Writes, and Read-Modify-Writes
- HMOS Technology for Low Power
- 68 Pin Leadless JEDEC Package
- Single +5V Supply

The HMOS 8206 Error Detection and Correction Unit is a high-speed device that provides error detection and correction for memory systems (static and dynamic) requiring high reliability and performance. Each 8206 handles 8 or 16 data bits and up to 8 check bits. 8206's can be cascaded to provide correction and detection for up to 80 bits of data. Other 8206 features include the ability to handle byte writes, memory initialization, and error logging.

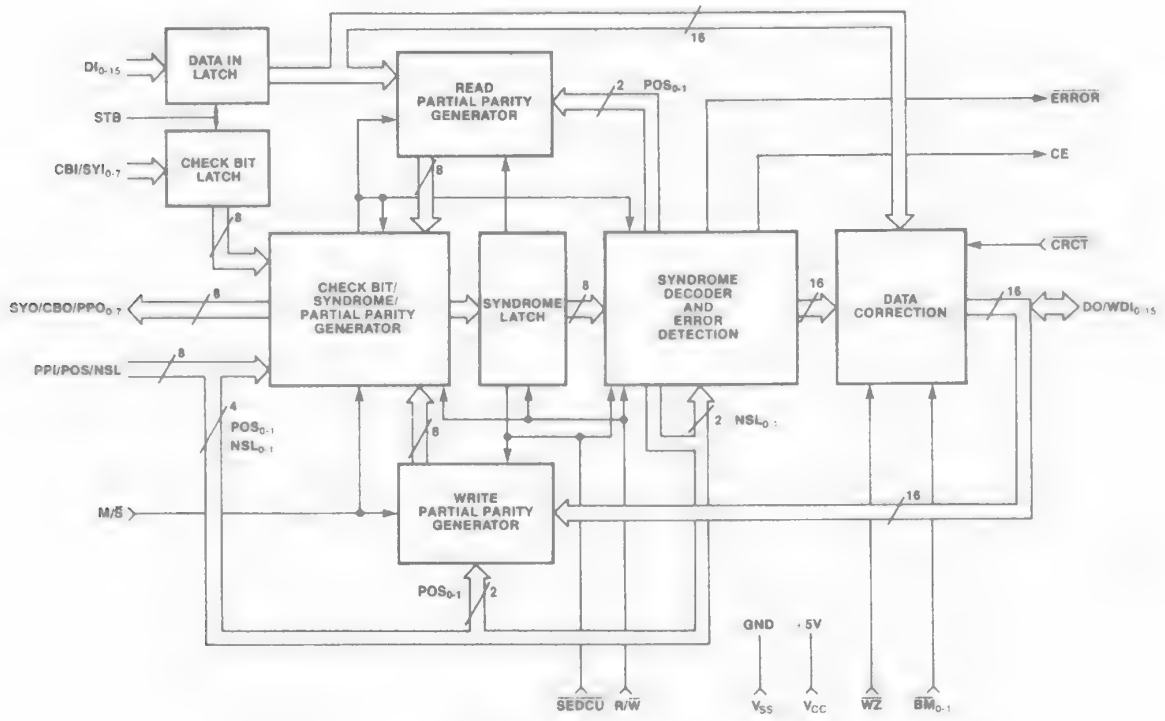

Figure 1. 8206 Block Diagram

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Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
DI_{0-15}	1, 68-61, 59-53	I	**Data In:** These inputs accept a 16 bit data word from RAM for error detection and/or correction.
CBI/SYI_0 CBI/SYI_1 CBI/SYI_2 CBI/SYI_3 CBI/SYI_4 CBI/SYI_5 CBI/SYI_6 CBI/SYI_7	5 6 7 8 9 10 11 12	I I I I I I I I	**Check Bits In/Syndrome In:** In a single 8206 system, or in the master in a multi-8206 system, these inputs accept the check bits (5 to 8) from the RAM. In a single 8206 16 bit system, CBI_{0-5} are used. In slave 8206's these inputs accept the syndrome from the master.
DO/WDI_0 DO/WDI_1 DO/WDI_2 DO/WDI_3 DO/WDI_4 DO/WDI_5 DO/WDI_6 DO/WDI_7 DO/WDI_8 DO/WDI_9 DO/WDI_{10} DO/WDI_{11} DO/WDI_{12} DO/WDI_{13} DO/WDI_{14} DO/WDI_{15}	51 50 49 48 47 46 45 44 42 41 40 39 38 37 36 35	I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O	**Data Out/Write Data In:** In a read cycle, data accepted by DI_{0-15} appears at these outputs corrected if $\overline{CRCT}$ is low, or uncorrected if $\overline{CRCT}$ is high. The $\overline{BM}$ inputs must be high to enable the output buffers during the read cycle. In a write cycle, data to be written into the RAM is accepted by these inputs for computing the write check bits. In a partial-write cycle, the byte not to be modified appears at either DO_{0-7} if $\overline{BM}_0$ is high, or DO_{8-15} if $\overline{BM}_1$ is high, for writing to the RAM. When $\overline{WZ}$ is active, it causes the 8206 to output all zeros at DO_{0-15}, with the proper write check bits on CBO.
$SYO/CBO/PPO_0$ $SYO/CBO/PPO_1$ $SYO/CBO/PPO_2$ $SYO/CBO/PPO_3$ $SYO/CBO/PPO_4$ $SYO/CBO/PPO_5$ $SYO/CBO/PPO_6$ $SYO/CBO/PPO_7$	23 24 25 27 28 29 30 31	O O O O O O O O	**Syndrome Out/Check Bits Out/Partial Parity Out:** In a single 8206 system, or in the master in a multi-8206 system, the syndrome appears at these outputs during a read. During a write, the write check bits appear. In slave 8206's the partial parity bits used by the master appear at these outputs. The syndrome is latched (during read-modify-writes) by $R/\overline{W}$ going low.
PPI_0/POS_0 PPI_1/POS_1	13 14	I I	**Partial Parity In/Position:** In the master in a multi-8206 system, these inputs accept partial parity bits 0 and 1 from the slaves. In a slave 8206 these inputs inform it of its position within the system (1 to 4). Not used in a single 8206 system.
PPI_2/NSL_0 PPI_3/NSL_1	15 16	I I	**Partial Parity In/Number of Slaves:** In the master in a multi-8206 system, these inputs accept partial parity bits 2 and 3 from the slaves. In a multi-8206 system these inputs are used in slave number 1 to tell it the total number of slaves in the system (1 to 4). Not used in other slaves or in a single 8206 system.
PPI_4/CE	17	I/O	**Partial Parity In/Correctable Error:** In the master in a multi-8206 system this pin accepts partial parity bit 4. In slave number 1 only, or in a single 8206 system, this pin outputs the correctable error flag. CE is latched by $R/\overline{W}$ going low. Not used in other slaves.
PPI_5 PPI_6 PPI_7	18 19 20	I I I	**Partial Parity In:** In the master in a multi-8206 system these pins accept partial parity bits 5 to 7. The number of partial parity bits equals the number of check bits. Not used in single 8206 systems or in slaves.
$\overline{ERROR}$	22	O	**Error:** This pin outputs the error flag in a single 8206 system or in the master of a multi-8206 system. It is latched by $R/\overline{W}$ going low. Not used in slaves.
$\overline{CRCT}$	52	I	**Correct:** When low this pin causes data correction during a read or read-modify-write cycle. When high, it causes error correction to be disabled, although error checking is still enabled.
STB	2	I	**Strobe:** STB is an input control used to strobe data at the DI inputs and check-bits at the CBI/SYI inputs. The signal is active high to admit the inputs. The signals are latched by the high-to-low transition of STB.

Table 1. Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{BM}_0$ $\overline{BM}_1$	33 32	I I	**Byte Marks:** When high, the Data Out pins are enabled for a read cycle. When low, the Data Out buffers are tristated for a write cycle. $\overline{BM}_0$ controls DO_{0-7}, while $\overline{BM}_1$ controls DO_{8-15}. In partial (byte) writes, the byte mark input is low for the new byte to be written.
$R/\overline{W}$	21	I	**Read/Write:** When high this pin causes the 8206 to perform detection and correction (if $\overline{CRCT}$ is low). When low, it causes the 8206 to generate check bits. On the high-to-low transition the syndrome is latched internally for read-modify-write cycles.
$\overline{WZ}$	34	I	**Write Zero:** When low this input overrides the $\overline{BM}_{0-1}$ and $R/\overline{W}$ inputs to cause the 8206 to output all zeros at DO_{0-15} with the corresponding check bits at CBO_{0-7}. Used for memory initialization.
$M/\overline{S}$	4	I	**Master/Slave:** Input tells the 8206 whether it is a master (high) or a slave (low).
$\overline{SEDCU}$	3	I	**Single EDC Unit:** Input tells the master whether it is operating as a single 8206 (low) or as the master in a multi-8206 system (high). Not used in slaves.
V_{CC}	10	I	**Power Supply:** +5V
V_{SS}	26	I	**Logic Ground**
V_{SS}	43	I	**Output Driver Ground**

FUNCTIONAL DESCRIPTION

The 8206 Error Detection and Correction Unit provides greater memory system reliability through its ability to detect and correct memory errors. It is a single chip device that can detect and correct all single bit errors and detect all double bit and some higher multiple bit errors. Some other odd multiple bit errors (e.g., 5 bits in error) are interpreted as single bit errors, and the CE flag is raised. While some even multiple bit errors (e.g., 4 bits in error) are interpreted as no error, most are detected as double bit errors. This error handling is a function of the number of check bits used by the 8206 (see Figure 2) and the specific Hamming code used. Errors in check bits are not distinguished from errors in a word.

For more information on error correction codes, see Intel Application Notes AP-46 and AP-73.

DATA WORD BITS	CHECK BITS
8	5
16	6
24	6
32	7
40	7
48	8
56	8
64	8
72	8
80	8

Figure 2. Number of Check Bits Used by 8206

A single 8206 handles 8 or 16 bits of data, and up to 5 8206's can be cascaded in order to handle data paths of 80 bits. For a single 8206 8 bit system, the DI_{8-15}, DO/WDI_{8-15} and $\overline{BM}_1$ inputs are grounded. See the Multi-Chip systems section for information on 24-80 bit systems.

The 8206 has a "flow through" architecture. It supports two kinds of error correction architecture: 1) Flow-through, or correct-always; and 2) Parallel, or check-only. There are two separate 16-pin busses, one to accept data from the RAM (DI) and the other to deliver corrected data to the system bus (DO/WDI). The logic is entirely combinatorial during a read cycle. This is in contrast to an architecture with only one bus, with bidirectional bus drivers that must first read the data and then be turned around to output the corrected data. The latter architecture typically requires additional hardware (latches and/or transceivers) and may be slower in a system due to timing skews of control signals.

READ CYCLE

With the R/$\overline{W}$ pin high, data is received from the RAM outputs into the DI pins where it is optionally latched by the STB signal. Check bits are generated from the data bits and compared to the check bits read from the RAM into the CBI pins. If an error is detected the $\overline{ERROR}$ flag is activated and the correctable error flag (CE) is used to inform the system whether the error was correctable or not. With the $\overline{BM}$ inputs high, the word appears corrected at the DO pins if the error was correctable, or unmodified if the error was uncorrectable.

If more than one 8206 is being used, then the check bits are read by the master. The slaves generate a partial parity output (PPO) and pass it to the master. The master 8206 then generates and returns the syndrome to the slaves (SYO) for correction of the data.

The 8206 may alternatively be used in a "check-only" mode with the $\overline{CRCT}$ pin left high. With the correction facility turned off, the propagation delay from memory outputs to 8206 outputs is significantly shortened. In this mode the 8206 issues an $\overline{ERROR}$ flag to the CPU, which can then perform one of several options: lengthen the current cycle for correction, restart the instruction, perform a diagnostic routine, etc.

A syndrome word, five to eight bits in length and containing all necessary information about the existence and location of an error, is made available to the system at the SYO_{0-7} pins. Error logging may be accomplished by latching the syndrome and the memory address of the word in error.

WRITE CYCLE

For a full write, in which an entire word is written to memory, the data is written directly to the RAM, bypassing the 8206. The same data enters the 8206 through the WDI pins where check bits are generated. The Byte Mark inputs must be low to tristate the DO drivers. The check bits, 5 to 8 in number, are then written to the RAM through the CBO pins for storage along with the data word. In a multi-chip system, the master writes the check bits using partial parity information from the slaves.

In a partial write, part of the data word is overwritten, and part is retained in memory. This is accomplished by performing a read-modify-write cycle. The complete old word is read into the 8206 and corrected, with the syndrome internally latched by R/$\overline{W}$ going low. Only that part of the word not to be modified is output onto the DO pins, as controlled by the Byte Mark inputs. That portion of the word to be overwritten is supplied by the system bus. The 8206 then calculates check bits for the new word, using the byte from the previous read and the new byte from the system bus, and writes them to the memory.

READ-MODIFY-WRITE CYCLES

Upon detection of an error the 8206 may be used to correct the bit in error in memory. This reduces the probability of getting multiple-bit errors in subsequent read cycles. This correction is handled by executing read-modify-write cycles.

The read-modify-write cycle is controlled by the R/$\overline{W}$ input. After (during) the read cycle, the system dynamic RAM controller or CPU examines the 8206 $\overline{ERROR}$ and CE outputs to determine if a correctable error occurred. If it did, the dynamic RAM controller or CPU forces R/$\overline{W}$ low, telling the 8206 to latch the generated syndrome and drive the corrected check bits onto the CBO outputs. The corrected data is available on the DO pins. The DRAM controller then writes the corrected data and corresponding check bits into memory.

The 8206 may be used to perform read-modify-writes in one or two RAM cycles. If it is done in two cycles, the 8206 latches are used to hold the data and check bits from the read cycle to be used in the following write cycle. The Intel 8207 Advanced Dynamic RAM controller allows read-modify-write cycles in one memory cycle. See the System Environment section.

INITIALIZATION

A memory system operating with ECC requires some form of initialization at system power-up in order to set valid data and check bit information in memory. The 8206 supports memory initialization by the write zero function. By activating the $\overline{WZ}$ pin, the 8206 will write a data pattern of zeros and the associated check bits in the current write cycle. By thus writing to all memory at power-up, a controller can set memory to valid data and check bits. Massive memory failure, as signified by both data and check bits all ones or zeros, will be detected as an uncorrectable error.

MULTI-CHIP SYSTEMS

A single 8206 handles 8 or 16 bits of data and 5 or 6 check bits, respectively. Up to 5 8206's can be cascaded for 80 bit memories with 8 check bits.

When cascaded, one 8206 operates as a master, and all others as slaves. As an example, during a read cycle in a 32 bit system with one master and one slave, the slave calculates parity on its portion of the word—"partial parity"—and presents it to the master through the PPO pins. The master combines the partial parity from the slave with the parity it calculated from its own portion of the word to generate the syndrome. The syndrome is then returned by the master to the slave for error correction. In systems with more than one slave the above description continues to apply, except that the partial parity outputs of the slaves must be XOR'd externally. Figure 3 shows the necessary external logic for multi-chip systems. Write and read-modify-write cycles are carried out analogously. See the System Operation section for multi-chip wiring diagrams.

There are several pins used to define whether the 8206 will operate as a master or a slave. Tables 2 and 3 illustrate how these pins are tied.

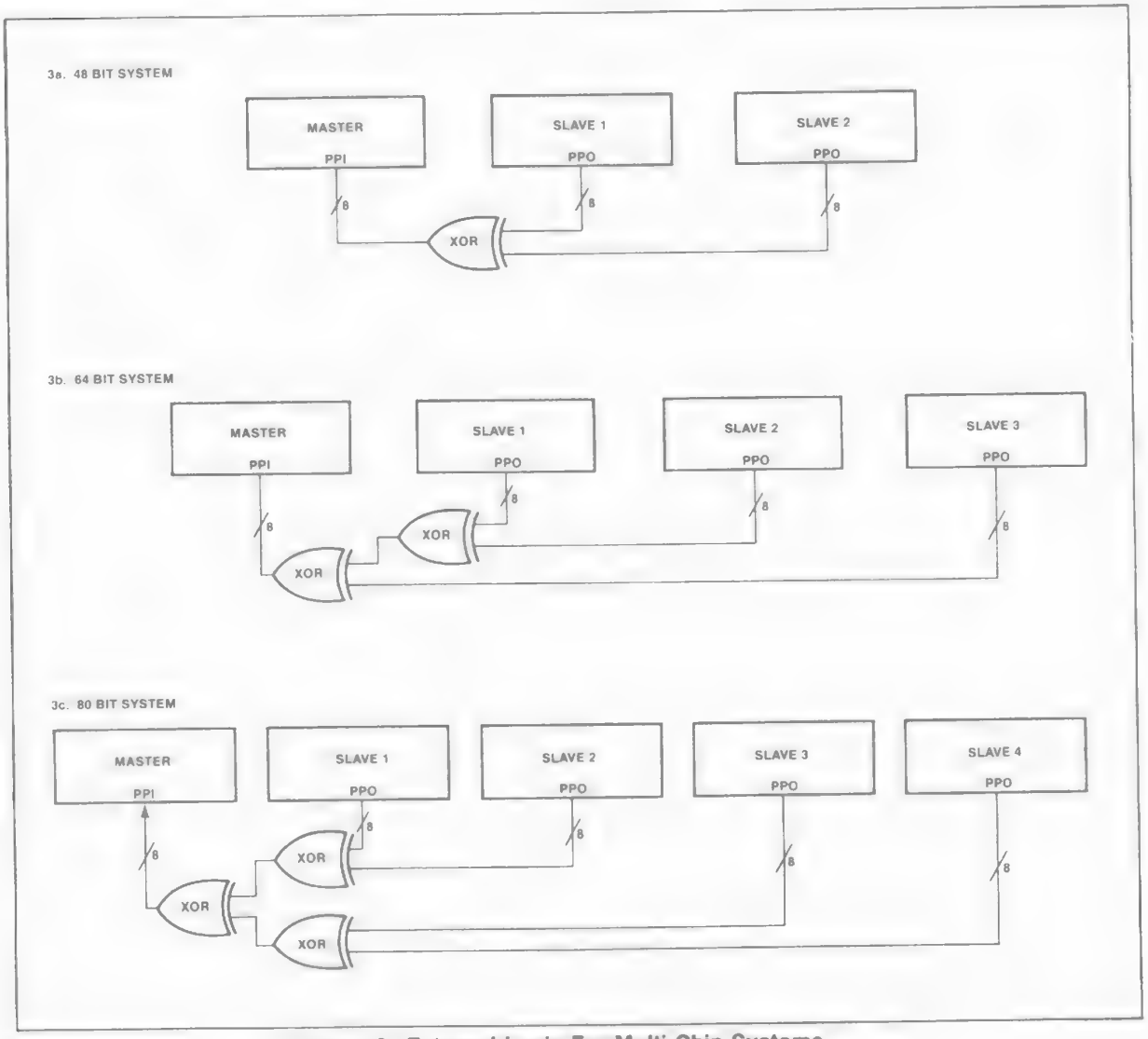

Figure 3. External Logic For Multi-Chip Systems

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Table 2. Master/Slave Pin Assignments

Pin No.	Pin Name	Master	Slave 1	Slave 2	Slave 3	Slave 4
4	$M/\overline{S}$	+5V	Gnd	Gnd	Gnd	Gnd
3	$\overline{SEDCU}$	+5V	+5V	+5V	+5V	+5V
13	PPI_0/POS_0	PPI	Gnd	+5V	Gnd	+5V
14	PPI_1/POS_1	PPI	Gnd	Gnd	+5V	+5V
15	PPI_2/NSL_0	PPI	*	+5V	+5V	+5V
16	PPI_3/NSL_1	PPI	*	+5V	+5V	+5V

*See Table 3.

NOTE:
Pins 13, 14, 15, 16 have internal pull-up resistors and may be left as N.C. where specified as connecting to +5V.

Table 3. NSL Pin Assignments for Slave 1

	Number of Slaves			
Pin	1	2	3	4
PPI_2/NSL_0	Gnd	+5V	Gnd	+5V
PPI_3/NSL_1	Gnd	Gnd	+5V	+5V

The timing specifications for multi-chip systems must be calculated to take account of the external XOR gating in 3, 4, and 5-chip systems. Let tXOR be the delay for a single external TTL XOR gate. Then the following equations show how to calculate the relevant timing parameters for 2-chip (n=0), 3-chip (n=1), 4-chip (n=2), and 5-chip (n=2) systems:

Data-in to corrected data-out (read cycle) =
TDVSV + TPVSV + TSVQV + ntXOR

Data-in to error flag (read cycle) =
TDVSV + TPVEV + ntXOR

Data-in to correctable error flag (read cycle) =
TDVSV + TPVSV + TSVCV + ntXOR

Write data to check-bits valid (full write cycle) =
TQVQV + TPVSV + ntXOR

Data-in to check-bits valid (read-mod-write cycle) =
TDVSV + TPVSV + TSVQV + TQVQV + TPVSV + 2ntXOR

Data-in to check-bits valid (non-correcting read-modify-write cycle) =
TDVQU + TQVQV + TPVSV + ntXOR

HAMMING CODE

The 8206 uses a modified Hamming code which was optimized for multi-chip EDCU systems. The code is such that partial parity is computed by all 8206's in parallel. No 8206 requires more time for propagation through logic levels than any other one, and hence no one device becomes a bottleneck in the parity operation. However, one or two levels of external TTL XOR gates are required in systems with three to five chips. The code appears in Table 4. The check bits are derived from the table by XORing or XNORing together the bits indicated by 'X's in each row corresponding to a check bit. For example, check bit 0 in the MASTER for data word 1000110101101011 will be "0." It should be noted that the 8206 will detect the gross-error condition of all lows or all highs.

Error correction is accomplished by identifying the bad bit and inverting it. Table 4 can also be used as an error syndrome table by replacing the 'X's with '1's. Each column then represents a different syndrome word, and by locating the column corresponding to a particular syndrome the bit to be corrected may be identified. If the syndrome cannot be located then the error cannot be corrected. For example, if the syndrome word is 00110111, the bit to be corrected is bit 5 in the slave one data word (bit 21).

The syndrome decoding is also summarized in Table 5, which can be used for error logging. By finding the appropriate syndrome word (starting with bit zero, the least significant bit), the result is either: 1) no error; 2) an identified (correctable) single bit error; 3) a double bit error; or 4) a multi-bit uncorrectable error.

Table 4. Modified Hamming Code Check Bit Generation

Check bits are generated by XOR'ing (except for the CB0 and CB1 data bits, which are XNOR'ed in the Master) the data bits in the rows corresponding to the check bits. Note there are 6 check bits in a 16-bit system, 7 in a 32-bit system, and 8 in 48-or-more-bit systems.

BYTE NUMBER		0								1								OPERATION
BIT NUMBER		0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	
CHECK BITS	CB0	x	x	-	x	-	x	x	-	x	-	-	x	-	x	-	-	XNOR
	CB1	x	-	x	-	-	x	-	x	-	x	-	x	x	-	x	-	XNOR
	CB2	-	x	x	-	x	-	x	x	-	-	x	-	x	-	-	x	XOR
	CB3	x	x	x	x	x	-	-	-	x	x	x	-	-	-	-	-	XOR
	CB4	-	-	-	x	x	x	x	x	-	-	-	-	-	x	x	x	XOR
	CB5	-	-	-	-	-	-	-	-	x	x	x	x	x	x	x	x	XOR
	CB6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	XOR
	CB7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	XOR
DATA BITS		0 0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0	1 1	1 2	1 3	1 4	1 5	

16 BIT OR MASTER

	2								3								OPERATION
	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	
CB0	-	x	x	x	-	x	x	-	-	x	x	-	-	x	-	-	XOR
CB1	x	x	x	-	-	x	-	x	x	x	-	-	-	-	-	x	XOR
CB2	-	x	x	x	-	x	x	x	-	-	x	x	-	-	-	-	XOR
CB3	x	x	-	-	x	-	x	x	x	-	-	x	x	-	-	-	XOR
CB4	x	x	-	-	x	x	x	x	-	-	-	-	x	-	x	-	XOR
CB5	-	-	-	x	x	x	x	x	-	-	-	-	-	x	x	x	XOR
CB6	-	-	-	-	-	-	-	-	x	x	x	x	x	x	x	x	XOR
CB7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	XOR
DATA BITS	1 6	1 7	1 8	1 9	2 0	2 1	2 2	2 3	2 4	2 5	2 6	2 7	2 8	2 9	3 0	3 1	

SLAVE #1

BYTE NUMBER		4								5								6								7								8								9								OPERATION
BIT NUMBER		0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	
CHECK BITS	CB0	x	x	-	x	-	x	x	-	x	-	-	x	-	x	-	-	x	-	x	x	x	-	x	-	x	-	x	x	-	-	x	-	-	x	x	x	-	x	x	-	-	x	x	-	-	x	-	-	XOR
	CB1	x	-	x	-	-	x	-	x	-	x	-	x	x	-	x	-	-	x	x	-	-	-	x	x	x	x	x	-	-	-	x	-	-	x	x	x	-	x	x	x	-	-	x	x	-	-	-	-	XOR
	CB2	-	x	x	-	x	-	x	x	-	-	x	-	x	-	-	x	-	x	x	x	-	x	x	-	-	x	x	-	-	x	-	-	x	-	-	x	-	x	x	-	-	x	x	-	-	x	-	x	XOR
	CB3	x	x	x	x	x	-	-	-	x	x	x	-	-	-	-	-	x	-	x	-	-	x	x	-	x	x	-	-	x	x	-	x	-	x	x	x	x	-	-	-	x	x	-	-	-	x	-	-	XOR
	CB4	-	-	-	x	x	x	x	x	-	-	-	-	-	x	x	x	-	-	-	x	x	x	x	x	-	-	-	-	x	x	x	-	-	x	x	x	-	-	-	x	x	x	x	x	-	-	x	-	XOR
	CB5	x	x	x	x	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	x	x	x	x	x	x	-	x	x	x	x	-	x	-	-	-	x	-	-	-	x	XOR
	CB6	x	x	x	x	x	x	x	x	-	-	-	-	-	-	-	-	x	x	x	x	x	x	x	x	-	-	-	-	-	-	-	-	x	x	-	-	x	x	x	x	-	-	-	-	x	-	x	-	XOR
	CB7	-	-	-	-	-	-	-	-	x	x	x	x	x	x	x	x	-	-	-	-	-	-	-	-	x	x	x	x	x	x	x	x	-	-	-	-	-	-	-	-	x	x	x	x	x	x	x	x	XOR
DATA BITS		3 2	3 3	3 4	3 5	3 6	3 7	3 8	3 9	4 0	4 1	4 2	4 3	4 4	4 5	4 6	4 7	4 8	4 9	5 0	5 1	5 2	5 3	5 4	5 5	5 6	5 7	5 8	5 9	6 0	6 1	6 2	6 3	6 4	6 5	6 6	6 7	6 8	6 9	7 0	7 1	7 2	7 3	7 4	7 5	7 6	7 7	7 8	7 9	

SLAVE #2 SLAVE #3 SLAVE #4

Table 5. Syndrome Decoding

Syndrome Bits 7	6	5	4	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
0	0	0	0	N	CB0	CB1	D	CB2	D	D	18	CB3	D	D	0	D	1	2	D												
0	0	0	1	CB4	D	D	5	D	6	7	D	D	3	16	D	4	D	D	17												
0	0	1	0	CB5	D	D	11	D	19	12	D	D	8	9	D	10	D	D	67												
0	0	1	1	D	13	14	D	15	D	D	21	20	D	D	66	D	22	23	D												
0	1	0	0	CB6	D	D	25	D	26	49	D	D	48	24	D	27	D	D	50												
0	1	0	1	D	52	55	D	51	D	D	70	28	D	D	65	D	53	54	D												
0	1	1	0	D	29	31	D	64	D	D	69	68	D	D	32	D	33	34	D												
0	1	1	1	30	D	D	37	D	38	39	D	D	35	71	D	36	D	D	U												
1	0	0	0	CB7	D	D	43	D	77	44	D	D	40	41	D	42	D	D	U												
1	0	0	1	D	45	46	D	47	D	D	74	72	D	D	U	D	73	U	D												
1	0	1	0	D	59	75	D	79	D	D	58	60	D	D	56	D	U	57	D												
1	0	1	1	63	D	D	62	D	U	U	D	D	U	U	D	61	D	D	U												
1	1	0	0	D	U	U	D	U	D	D	U	76	D	D	U	D	U	U	D												
1	1	0	1	78	D	D	U	D	U	U	D	D	U	U	D	U	D	D	U												
1	1	1	0	U	D	D	U	D	U	U	D	D	U	U	D	U	D	D	U												
1	1	1	1	D	U	U	D	U	D	D	U	U	D	D	U	D	U	U	D												

N = No Error
CBX = Error in Check Bit X
X = Error in Data Bit X
D = Double Bit Error
U = Uncorrectable Multi-Bit Error

SYSTEM ENVIRONMENT

The 8206 interface to a typical 32 bit memory system is illustrated in Figure 4. For larger systems, the partial parity bits from slaves two to four must be

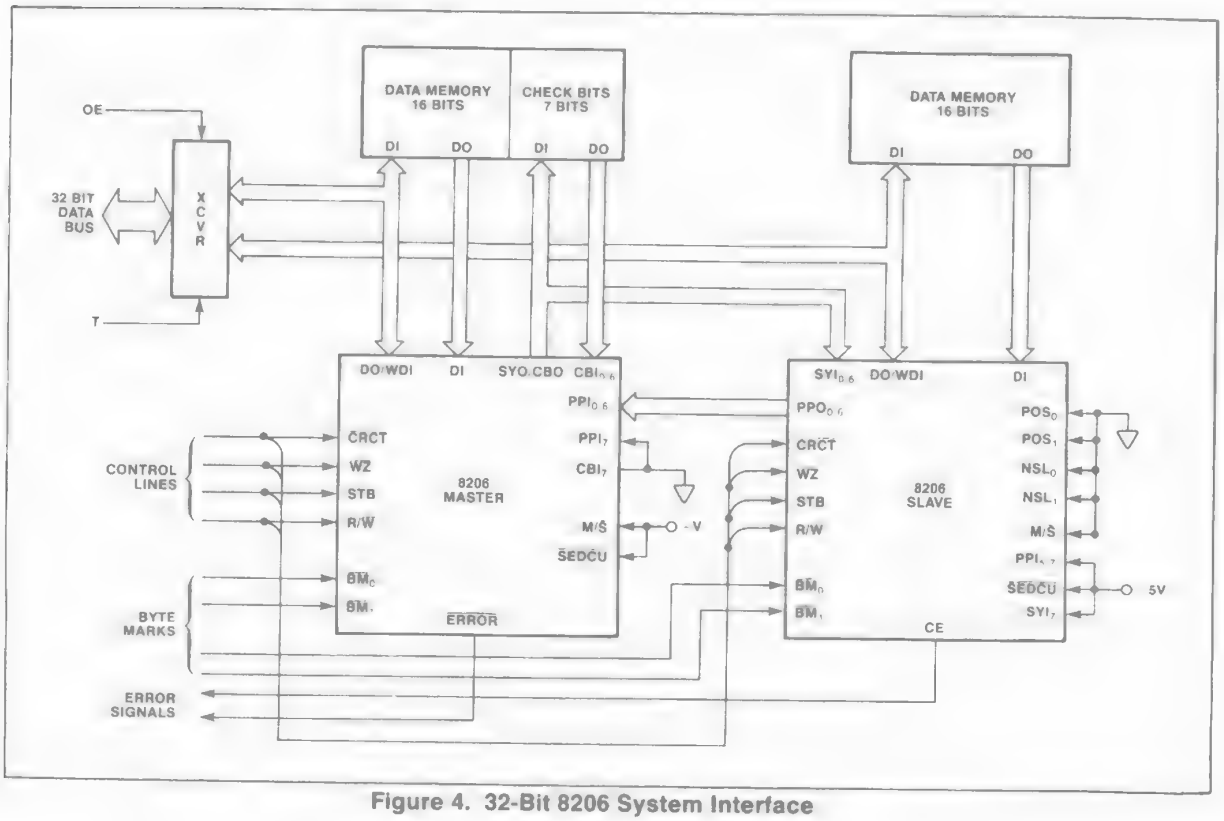

Figure 4. 32-Bit 8206 System Interface

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XOR'ed externally, which calls for one level of XOR gating for three 8206's and two levels for four or five 8206's.

The 8206 is designed for direct connection to the Intel 8207 Advanced Dynamic RAM Controller, due to be sampled in the first quarter of 1982. The 8207 has the ability to perform dual port memory control, and Figure 5 illustrates a highly integrated dual port RAM implementation using the 8206 and 8207. The 8206/8207 combination permits such features as automatic scrubbing (correcting errors in memory during refresh), extending RAS and CAS timings for Read-Modify-Writes in single memory cycles, and automatic memory initialization upon reset. Together these two chips provide a complete dual-port, error-corrected dynamic RAM subsystem.

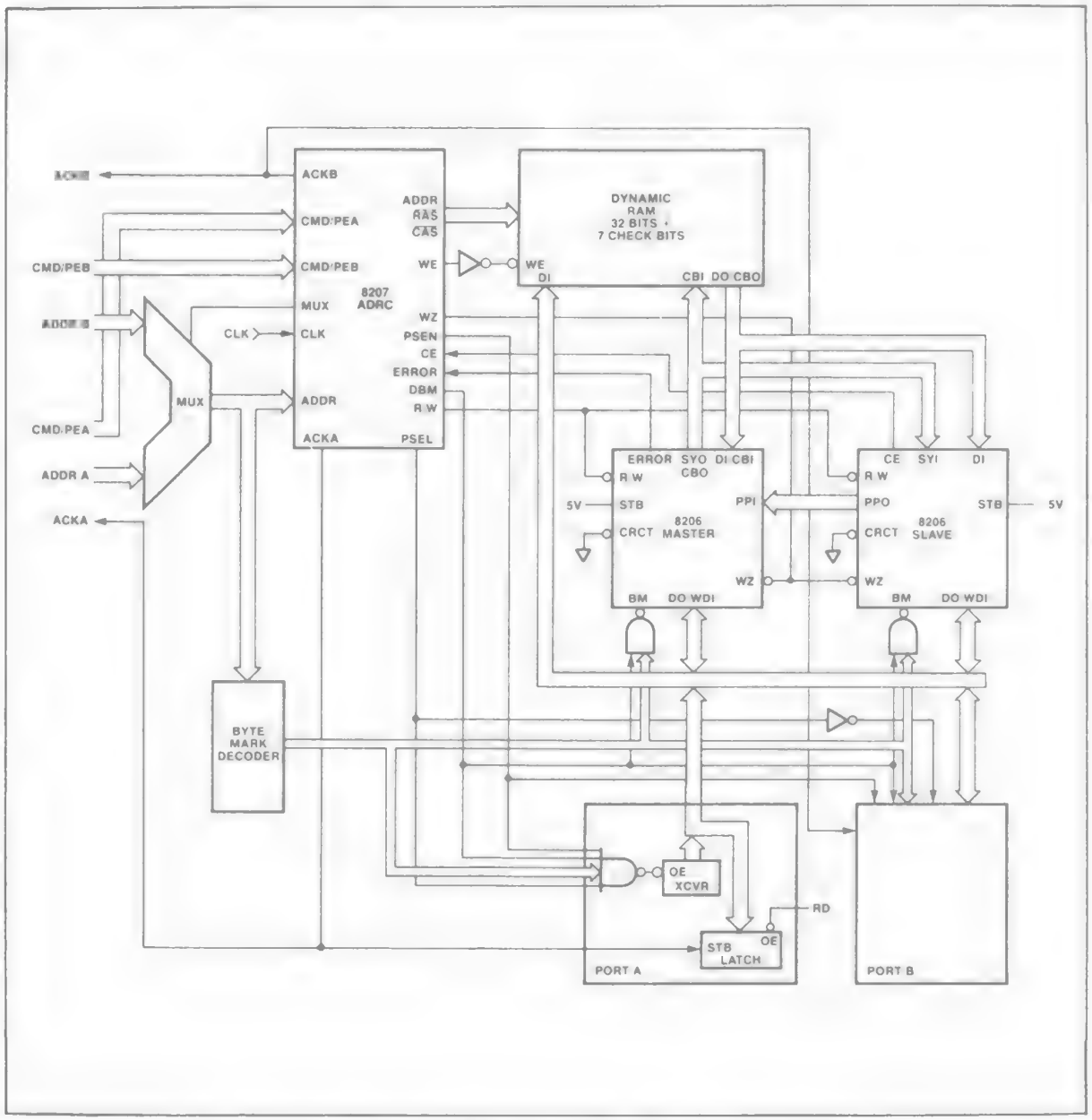

Figure 5. Dual Port RAM Subsystem with 8206/8207 (32-bit bus)

MEMORY BOARD TESTING

The 8206 lends itself to straightforward memory board testing with a minimum of hardware overhead. The following is a description of four common test modes and their implementation.

Mode 0—Read and write with error correction.
Implementation: This mode is the normal 8206 operating mode.

Mode 1—Read and write data with error correction disabled to allow test of data memory.
Implementation: This mode is performed with $\overline{CRCT}$ deactivated.

Mode 2—Read and write check bits with error correction disabled to allow test of check bits memory.
Implementation: Any pattern may be written into the check bits memory by judiciously choosing the proper data word to generate the desired check bits, through the use of the 8206 Hamming code. To read out the check bits it is first necessary to fill the data memory with all zeros, which may be done by activating $\overline{WZ}$ and incrementing memory addresses with $\overline{WE}$ to the check bits memory held inactive, and then performing ordinary reads. The check bits will then appear directly at the SYO outputs, with bits CB0 and CB1 inverted.

Mode 3—Write data, without altering or writing check bits, to allow the storage of bit combinations to cause error correction and detection.
Implementation: This mode is implemented by writing the desired word to memory with $\overline{WE}$ to the check bits array held inactive.

PACKAGE

The 8206 is packaged in a 68-pin, leadless JEDEC type A hermetic chip carrier. Figure 6 illustrates the package, and Figure 7 is the pinout.

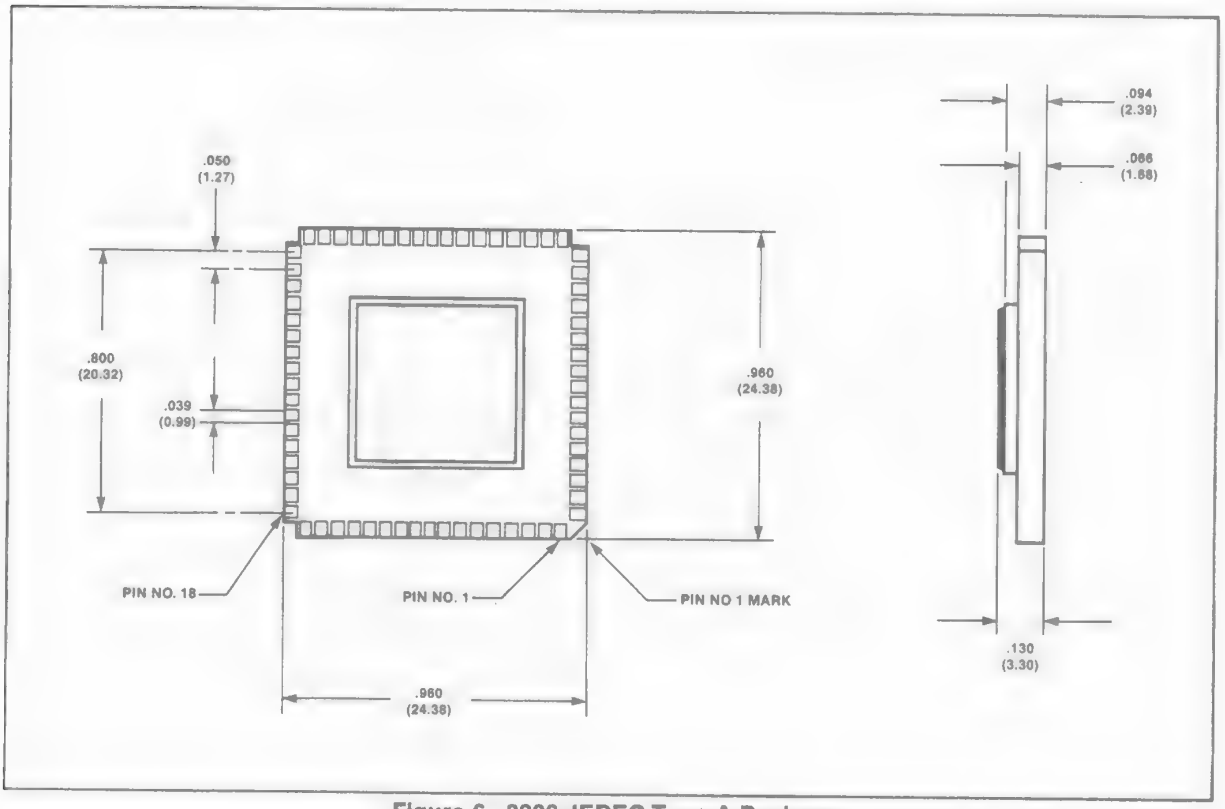

Figure 6. 8206 JEDEC Type A Package

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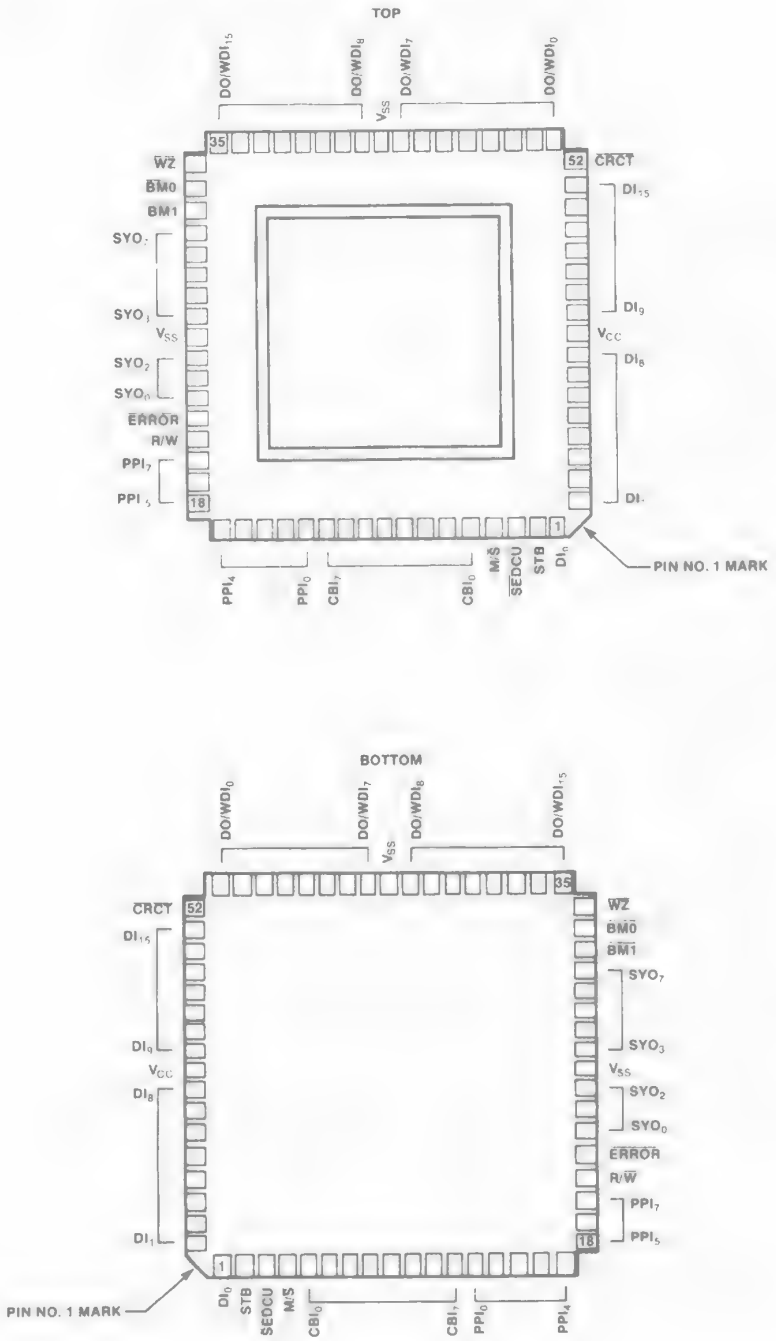


Figure 7. 8206 Pinout Diagram

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage On Any Pin
With Respect to Ground ..... −0.5V to +7V
Power Dissipation ..... 2.5 Watts

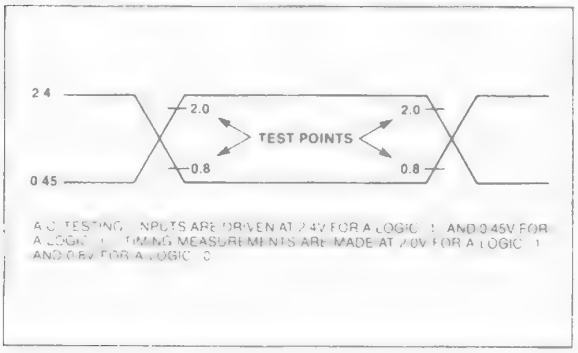
**NOTE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5.0V ± 10%, V_{SS} = GND)

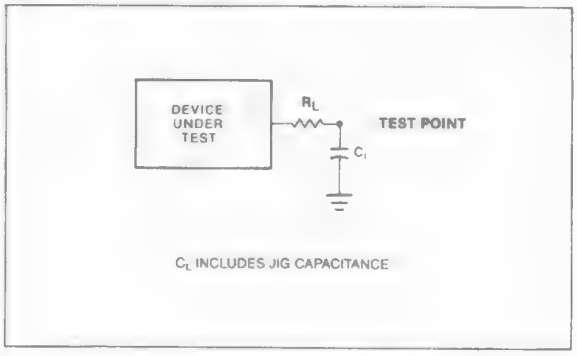
Symbol	Parameter	Min.	Max.	Unit	Test Conditions
I_{CC}	Power Supply Current —Single 8206 or Slave #1 —Master in Multi-Chip or Slaves #2, 3, 4		 270 230	 mA mA	
V_{IL}[1]	Input Low Voltage	−0.5	0.8	V	
V_{IH}[1]	Input High Voltage	2.0	V_{CC} + 0.5V	V	
V_{OL}	Output Low Voltage —DO —All Others		 0.4 0.4	 V V	 I_{OL} = 8mA I_{OL} = 2.0mA
V_{OH}	Output High Voltage —DO, CBO —All Other Outputs	 2.6 2.4		 V V	 I_{OH} = −2mA I_{OH} = −0.4mA
I_{LO}	I/O Leakage Current —PPI_4/CE —DO/WDI_{0-15}		 ± 20 ± 10	 μA μA	 0.45V ≤ $V_{I/O}$ ≤ V_{CC}
I_{LI}	Input Leakage Current —$PPI_{0-3,\ 5-7}$, CBI_{6-7}, $\overline{SEDCU}$[2] —All Other Input Only Pins		 ± 20 ± 10	 μA μA	 0V ≤ V_{IN} ≤ V_{CC}

NOTES:
1. $\overline{SEDCU}$ (pin 3) and M/$\overline{S}$ (pin 4) are device strapping options and should be tied to V_{CC} or GND. V_{IH} min = V_{CC} −0.5V and V_{IL} max = 0.5V.
2. PPI_{0-7} (pins 13–20) and CBI_{6-7} (pins 11, 12) have internal pull-up resistors and if left unconnected will be pulled to V_{CC}.

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING LOAD CIRCUIT



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A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = +5V ± 10%, V_{SS} = 0V, R_L = 22Ω, C_L = 50 pF; all times are in nsec.)

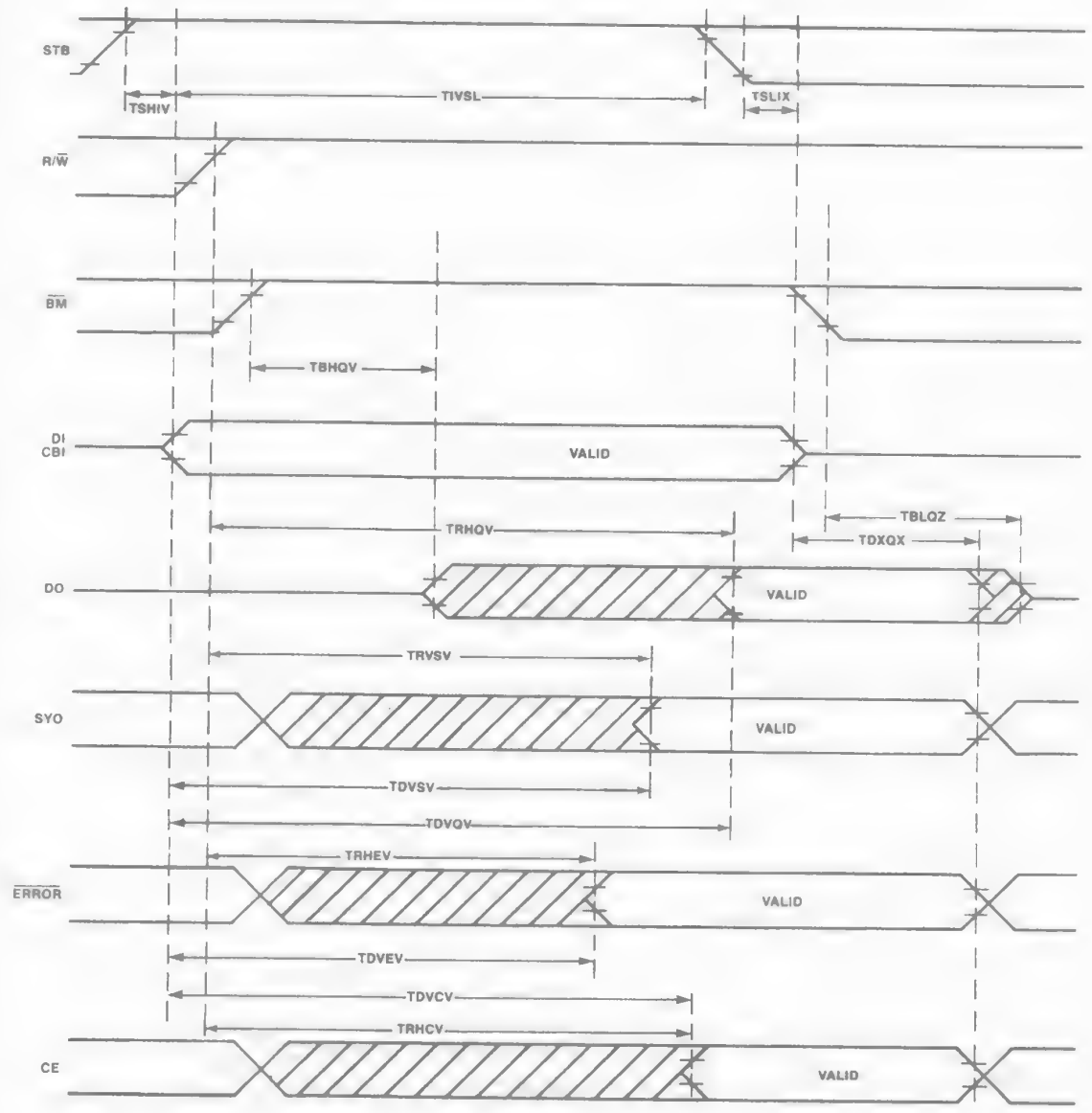
Symbol	Parameter	8206 Min.	8206 Max.	8206-8 Min.	8206-8 Max.	Notes
TRHEV	$\overline{ERROR}$ Valid from R/$\overline{W}$↑		25		34	
TRHCV	CE Valid from R/$\overline{W}$↑ (Single 8206)		44		59	
TRHQV	Corrected Data Valid from R/$\overline{W}$↑		54		66	1
TRVSV	SYO/CBO/PPO Valid from R/$\overline{W}$		42		56	1
TDVEV	$\overline{ERROR}$ Valid from Data/Check Bits In		52		70	
TDVCV	CE Valid from Data/Check Bits In		70		94	
TDVQV	Corrected Data Valid from Data/Check Bits In		67		90	
TDVSV	SYO/PPO Valid from Data/Check Bits In		55		74	
TBHQV	Corrected Data Access Time		37		43	
TDXQX	Hold Time from Data/check Bits In	0		0		1
TBLQZ	Corrected Data Float Delay	0	28	0	38	1
TSHIV	STB High to Data/Check Bits In Valid	30		40		2
TIVSL	Data/Check Bits In to STB↓ Set-up	5		5		
TSLIX	Data/Check Bits In from STB↓ Hold	25		30		
TPVEV	$\overline{ERROR}$ Valid from Partial Parity In		30		40	
TPVQV	Corrected Data (Master) from Partial Parity In		61		76	1
TPVSV	Syndrome/Check Bits Out from Partial Parity In		43		51	1
TSVQV	Corrected Data (Slave) Valid from Syndrome		51		69	
TSVCV	CE Valid from Syndrome (Slave number 1)		48		65	
TQVQV	Check Bits/Partial Parity Out from Write Data In		64		80	1
TRHSX	Check Bits/Partial Parity Out from R/W, $\overline{WZ}$ Hold	0		0		1
TRLSX	Syndrome Out from R/$\overline{W}$ Hold	0		0		
TQXQX	Hold Time from Write Data In	0		0		1
TSVRL	Syndrome Out to R/$\overline{W}$↓ Set-up	17		22		
TDVRL	Data/Check Bits In to R/$\overline{W}$ Set-up	39		46		1
TDVQU	Uncorrected Data Out from Data In		32		43	
TTVQV	Corrected Data Out from $\overline{CRCT}$↓		30		40	
TWLQL	$\overline{WZ}$↓ to Zero Out		30		40	
TWHQX	Zero Out from $\overline{WZ}$↑ Hold	0		0		

NOTES:

1. A.C. Test Levels for CBO and DO are 2.4V and 0.8V.
2. T_{SHIV} is required to guarantee output delay timings T_{DVEV}, T_{DVCV}, T_{DVQV}, T_{DVSV}. T_{SHIV} + T_{IVSL} guarantees a min STB pulse width of 35 ns (45 ns for the 8206-8).

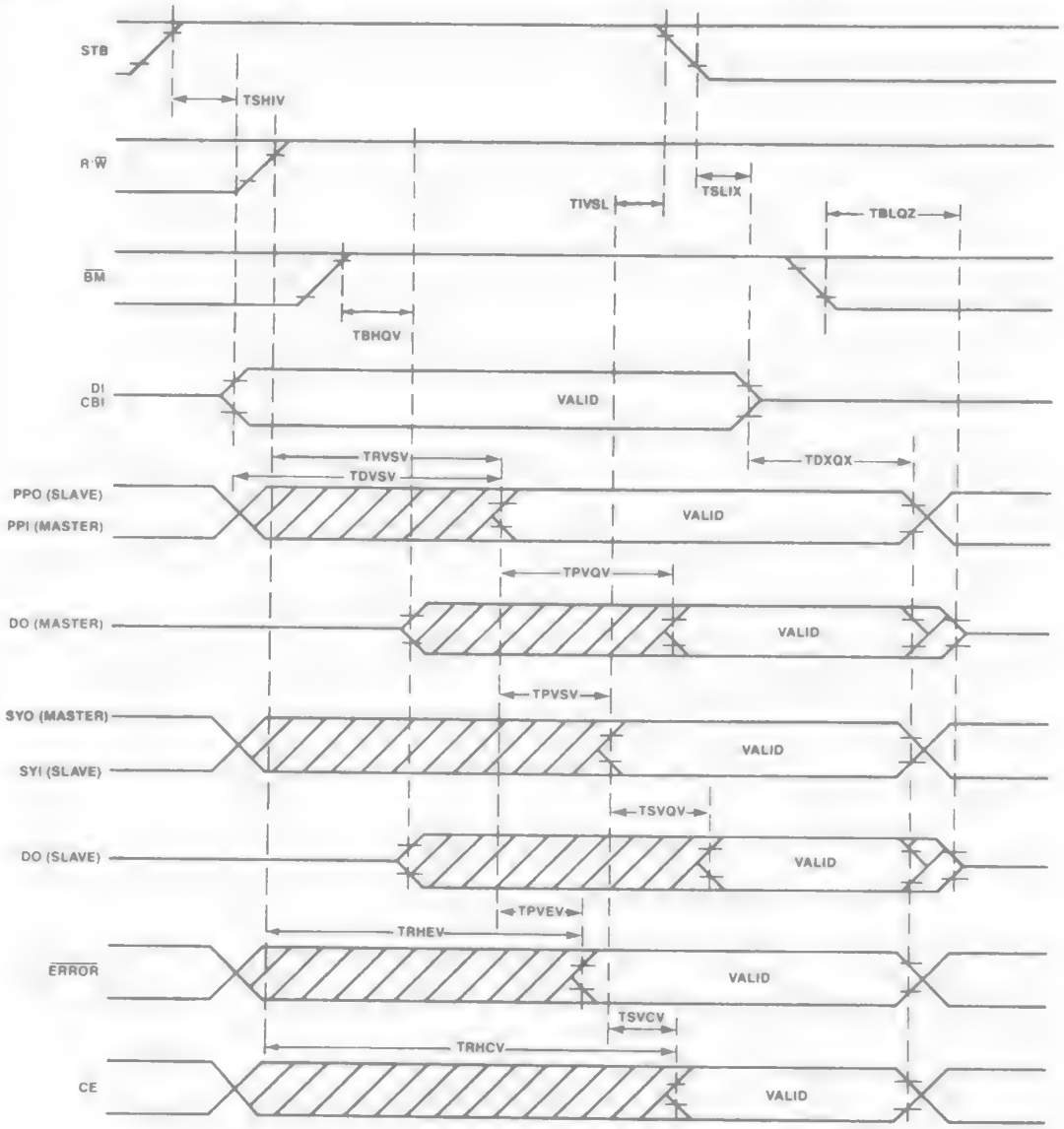
WAVEFORMS

READ—16 BIT ONLY



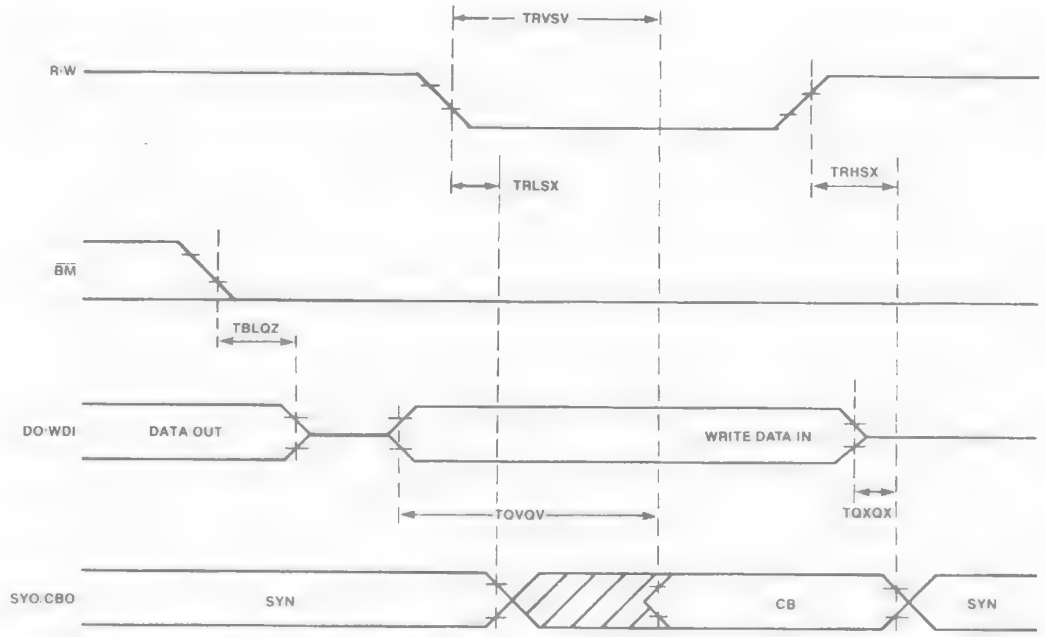
WAVEFORMS (Continued)

READ—MASTER/SLAVE

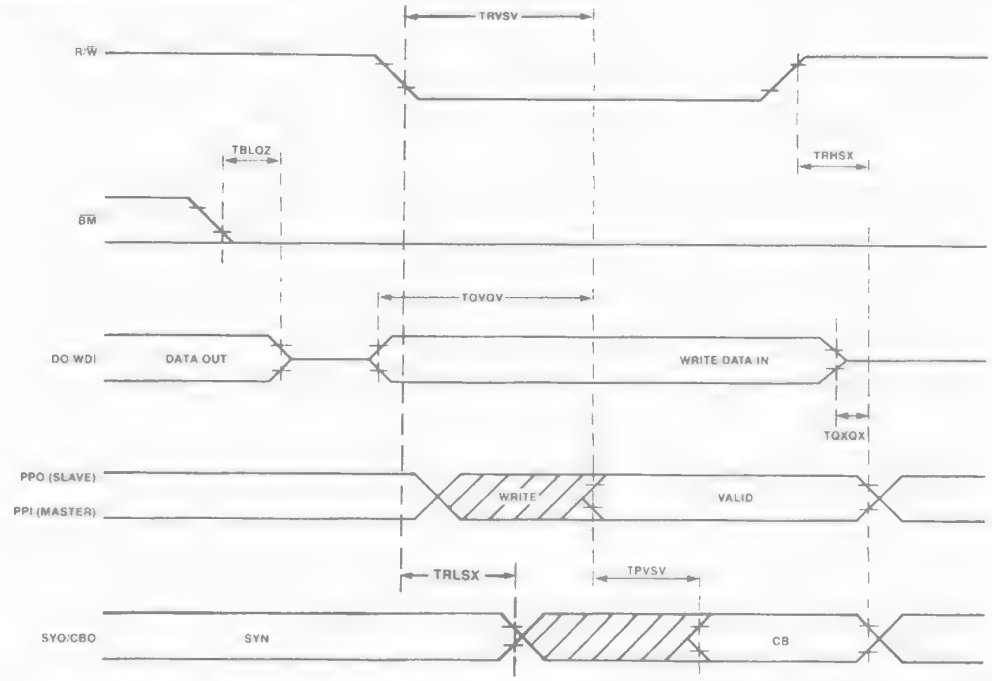


WAVEFORMS (Continued)

FULL WRITE—16 BIT ONLY



FULL WRITE—MASTER/SLAVE



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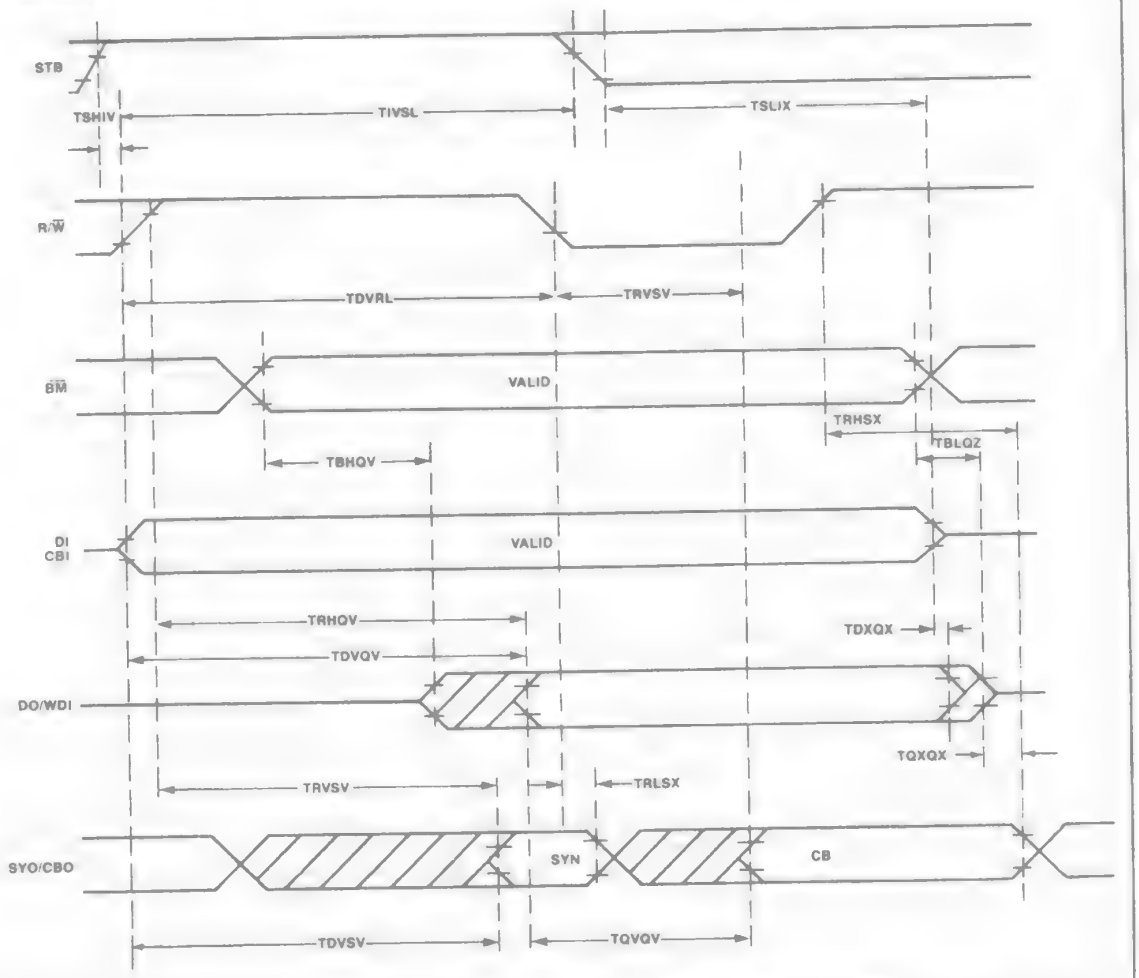
WAVEFORMS (Continued)

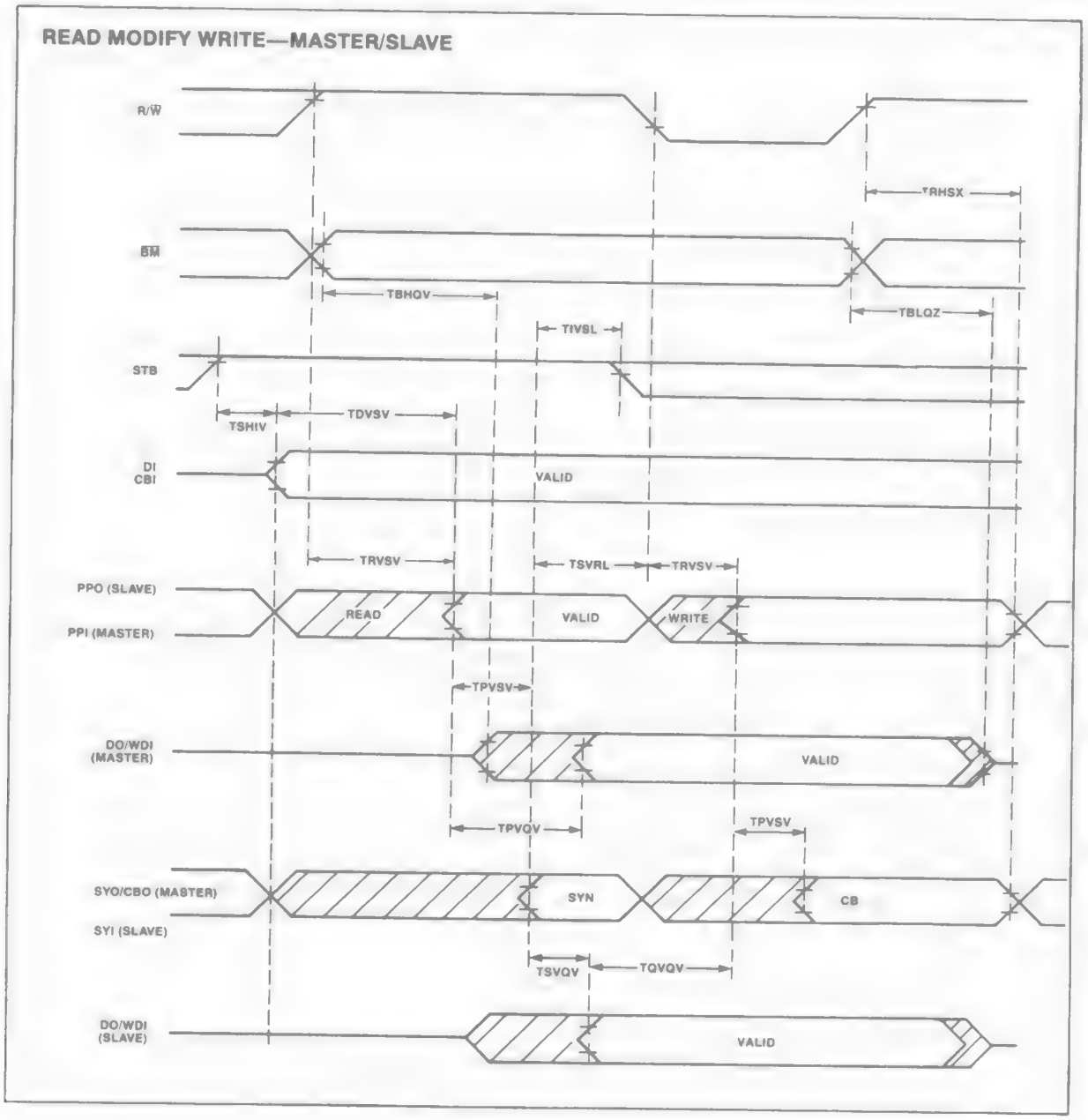
READ MODIFY WRITE—16 BIT ONLY



AFN-02009B

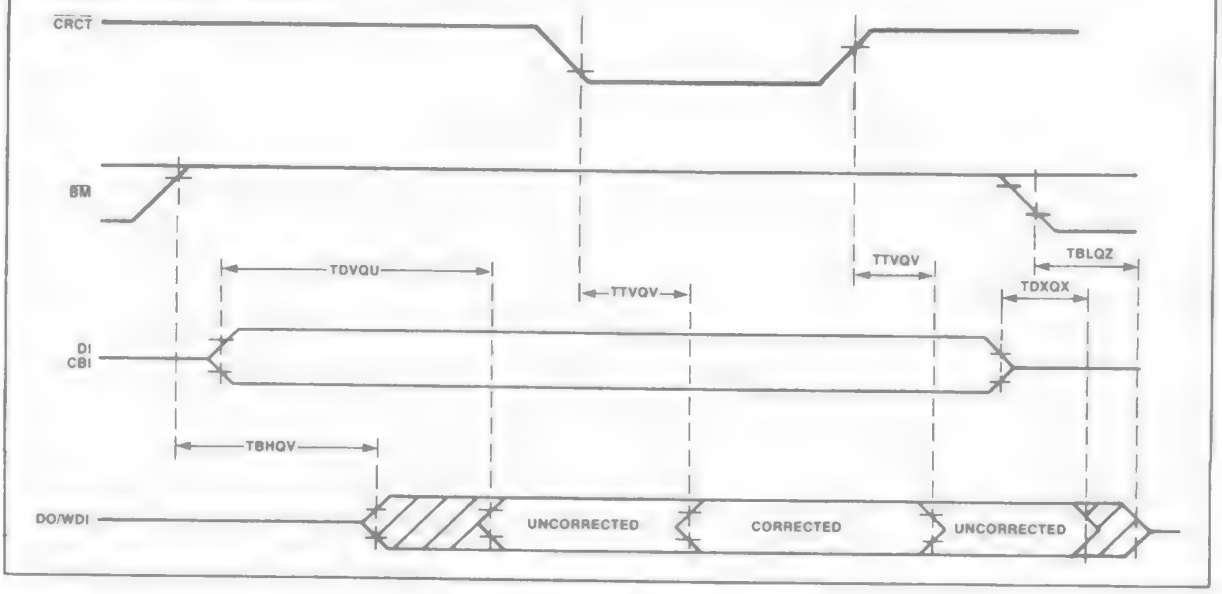
WAVEFORMS (Continued)

READ MODIFY WRITE—MASTER/SLAVE

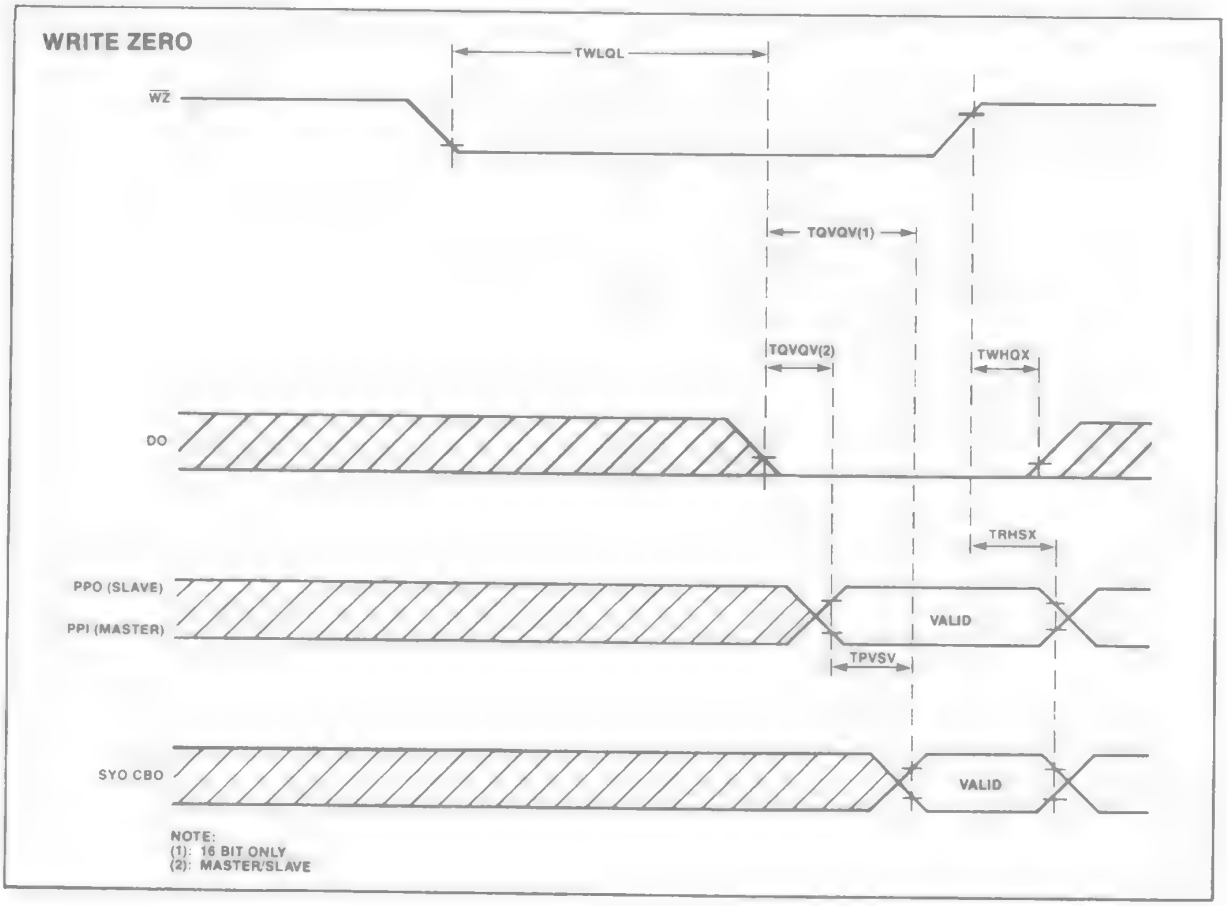


WAVEFORMS (Continued)

NON-CORRECTING READ



WRITE ZERO



NOTE:
(1): 16 BIT ONLY
(2): MASTER/SLAVE

ADVANCE INFORMATION

8207
ADVANCED DYNAMIC RAM CONTROLLER

- **Provides All Signals Necessary to Control 16K (2118), 64K (2164A) and 256K Dynamic RAMs**
- **Directly Addresses and Drives up to 2 Megabytes without External Drivers**
- **Supports Single and Dual-Port Configurations**
- **Automatic RAM Initialization in All Modes**
- **Five Programmable Refresh Modes**
- **Transparent Memory Scrubbing in ECC Mode**
- **Supports Intel iAPX 86, 88, 186, and 286 Microprocessors**
- **Data Transfer Acknowledge Signals for Each Port**
- **Provides Signals to Directly Control the 8206 Error Detection and Correction Unit**
- **Supports Synchronous or Asynchronous Operation on Either Port**
- **+5 Volt Only HMOSII Technology for High Performance and Low Power**

The Intel 8207 Advanced Dynamic RAM Controller (ADRC) is a high-performance, systems-oriented, Dynamic RAM controller that is designed to easily interface 16K, 64K and 256K Dynamic RAMs to Intel and other microprocessor Systems. A dual-port interface allows two different busses to independently access memory. When configured with an 8206 Error Detection and Correction Unit the 8207 supplies the necessary logic for designing large error-corrected memory arrays. This combination provides automatic memory initialization and transparent memory error scrubbing.

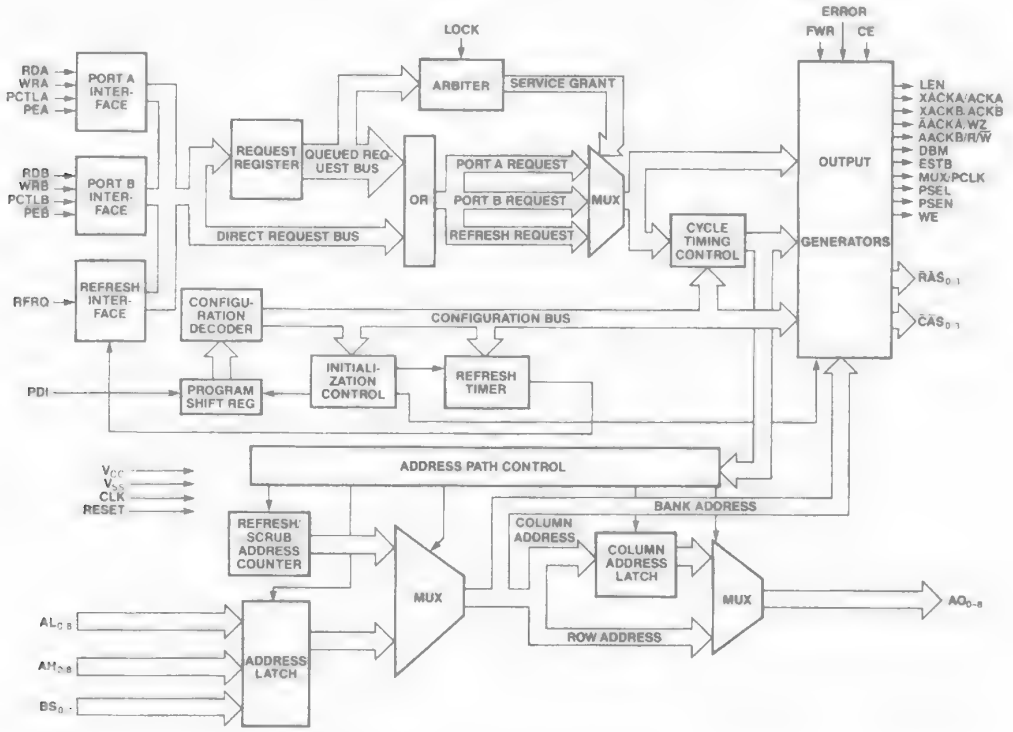


Figure 1. 8207 Block Diagram

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APRIL 1982
ORDER NUMBER: 210463-001

NOTICE: The pin descriptions are not final specifications and are subject to change.

Table 1. Pin Description

Symbol	Pin	Type	Name and Function
LEN	1	O	**ADDRESS LATCH ENABLE:** In two-port configurations, when port A is running with iAPX 286 Status interface mode, this output replaces the ALE signal from the system bus controller and generates an address latch enable signal which provides optimum setup and hold timing for the 8207.
$\overline{XACKA}$/ $\overline{ACKA}$	2	O	**TRANSFER ACKNOWLEDGE PORT A/ACKNOWLEDGE PORT A:** In non-ECC mode, this pin is $\overline{XACKA}$ and indicates that data on the bus is valid during a read cycle or that data may be removed from the bus during a write cycle for Port A. $\overline{XACKA}$ is a Multibus-compatible signal. In ECC mode, this pin is $\overline{ACKA}$ which can be configured, depending on the programming of the X program bit, as an XACK or AACK strobe. The SA programming bit determines whether AACK will be early or late.
$\overline{XACKB}$/ $\overline{ACKB}$	3	O	**TRANSFER ACKNOWLEDGE PORT B/ACKNOWLEDGE PORT B:** In non-ECC mode, this pin is $\overline{XACKB}$ and indicates that data on the bus is valid during a read cycle or that data may be removed from the bus during a write cycle for Port B. $\overline{XACKB}$ is a Multibus-compatible signal. In ECC mode, this pin is $\overline{ACKB}$ which can be configured, depending on the programming of the X program bit, as an XACK or AACK strobe. The SB programming bit determines whether AACK will be early or late.
$\overline{AACKA}$/ $\overline{WZ}$	4	O	**ADVANCED ACKNOWLEDGE PORT A/WRITE ZERO:** In non-ECC mode, this pin is $\overline{AACKA}$ and indicates that the processor may continue processing and that data will be available when required. This signal is optimized for the system by programming the SA program bit for synchronous or asynchronous operation. After a RESET, this signal will cause the 8206 to force the data to all zeros and generate the appropriate check bits.
$\overline{AACKB}$/ R/$\overline{W}$	5	O	**ADVANCED ACKNOWLEDGE PORT B/READ/WRITE:** In non-ECC mode, this pin is $\overline{AACKB}$ and indicates that the processor may continue processing and that data will be available when required. This signal is optimized for the system by programming the SB program bit for synchronous or asynchronous operation. This signal causes the 8206 EDCU to latch the syndrome and error flags and generate check bits.
$\overline{DBM}$	6	O	**DISABLE BYTE MARKS:** This is an ECC control output signal indicating that a read or refresh cycle is occurring. This output forces the byte address decoding logic to enable all 8206 data output buffers. In ECC mode, this output is also asserted during memory initialization and the 8-cycle dynamic RAM wake-up exercise.
$\overline{ESTB}$	7	O	**ERROR STROBE:** In ECC mode, this strobe is activated when an error is detected and allows a negative-edge triggered flip-flop to latch the status of the 8206 EDCU CE for systems with error logging capabilities.
LOCK	[redacted]	I	**LOCK:** This input instructs the 8207 to lock out the port not being serviced at the time LOCK was issued.
V_{CC}	[redacted] 43	I I	**LOGIC POWER:** +5 Volts ± 10%. Supplies V_{CC} for the internal logic circuits. **DRIVER POWER:** +5 Volts ± 10%. Supplies V_{CC} for the output drivers.
CE	10	I	**CORRECTABLE ERROR:** This is an ECC input from the 8206 EDCU which instructs the 8207 whether a detected error is correctable or not. A high input indicates a correctable error. A low input inhibits the 8207 from activating WE to write the data back into RAM. This should be connected to the CE output of the 8206.
$\overline{ERROR}$	11	I	**ERROR:** This is an ECC input from the 8206 EDCU and instructs the 8207 that an error was detected. This pin should be connected to the ERROR output of the 8206.
MUX/ PCLK	12	O	**MULTIPLEXER CONTROL/PROGRAMMING CLOCK:** Immediately after a RESET this pin is used to clock serial programming data into the PDI pin. In normal two-port operation, this pin is used to select memory addresses from the appropriate port. When this signal is high, port A is selected and when it is low, port B is selected. This signal may change state before the completion of a RAM cycle, but the RAM address hold time is satisfied.
PSEL	13	O	**PORT SELECT:** This signal is used to select the appropriate port for data transfer.
PSEN	14	O	**PORT SELECT ENABLE:** This signal used in conjunction with PSEL provides contention-free port exchange. When PSEN is low, PSEL is allowed to change state.
WE	15	O	**WRITE ENABLE:** This signal provides the dynamic RAM array the write enable input for a write operation.

NOTICE: The pin descriptions are not final specifications and are subject to change.

Table 1. Pin Description (Continued)

Symbol	Pin	Type	Name and Function
$\overline{FWR}$	16	I	**FULL WRITE:** This is an ECC input signal that instructs the 8207, in an ECC configuration, whether the present write cycle is normal RAM write (full write) or a RAM partial write (read-modify-write) cycle.
RESET	17	I	**RESET:** This signal causes all internal counters and state flip-flops to be reset and upon release of RESET, data appearing at the PDI pin is clocked in by the PCLK output. The states of the PDI, PCTLA, PCTLB and RFRQ pins are sampled by RESET going inactive and are used to program the 8207.
$\overline{CAS0}$ $\overline{CAS1}$ $\overline{CAS2}$ $\overline{CAS3}$	18 20 22 24	O O O O	**COLUMN ADDRESS STROBE:** These outputs are used by the dynamic RAM array to latch the column address, present on the AO0–8 pins. These outputs are selected by the BS0 and BS1 as programmed by program bits RB0 and RB1. These outputs drive the dynamic RAM array directly and need no external drivers.
$\overline{RAS0}$ $\overline{RAS1}$ $\overline{RAS2}$ $\overline{RAS3}$	19 21 23 25	O O O O	**ROW ADDRESS STROBE:** These outputs are used by the dynamic RAM array to latch the row address, present on the AO0–8 pins. These ouptuts are selected by the BS0 and BS1 as programmed by program bits RB0 and RB1. These outputs drive the dynamic RAM array directly and need no external drivers.
V_{SS}	26 60	I I	**DRIVER GROUND:** Provides a ground for the output drivers. **LOGIC GROUND:** Provides a ground for the remainder of the device.
AO0 AO1 AO2 AO3 AO4 AO5 AO6 AO7 AO8	35 34 33 32 31 30 29 28 27	O O O O O O O O O	**ADDRESS OUTPUTS:** These outputs are designed to provide the row and column addresses of the selected port to the dynamic RAM array. These outputs drive the dynamic RAM array directly and need no external drivers.
BS0 BS1	36 37	I I	**BANK SELECT:** These inputs are used to select one of four banks of the dynamic RAM array as defined by the program bits RB0 and RB1.
AL0 AL1 AL2 AL3 AL4 AL5 AL6 AL7 AL8	38 39 40 41 42 44 45 46 47	I I I I I I I I I	**ADDRESS LOW:** These lower-order address inputs are used to generate the row address for the internal address multiplexer.
AH0 AH1 AH2 AH3 AH4 AH5 AH6 AH7 AH8	[illegible] 49 50 51 52 53 54 55 56	I I I I I I I I I	**ADDRESS HIGH:** These higher-order address inputs are used to generate the column address for the internal address multiplexer.
PDI	57	I	**PROGRAM DATA INPUT:** This input programs the various user-selectable options in the 8207. The PCLK pin shifts programming data into the PDI input from optional external shift registers. This pin may be strapped high or low to a default ECC (PDI = V_{CC}) or non-ECC (PDI = Ground) mode configuration.
RFRQ	58	I	**REFRESH REQUEST:** This input is sampled on the falling edge of RESET. If it is high at RESET, then the 8207 is programmed for internal refresh request or external refresh request with failsafe protection. If it is low at RESET, then the 8207 is programmed for external refresh without failsafe protection or burst refresh. Once programmed the RFRQ pin accepts signals to start an external refresh with failsafe protection or external refresh without failsafe protection or a burst refresh.

NOTICE: The pin descriptions are not final specifications and are subject to change.

Table 1. Pin Description (Continued)

Symbol	Pin	Type	Name and Function
CLK	59	I	**CLOCK:** This input provides the basic timing for sequencing the internal logic.
$\overline{RDB}$	61	I	**READ FOR PORT B:** This pin is the read memory request command input for port B. This input also directly accepts the $\overline{S1}$ status line from Intel processors.
$\overline{WRB}$	62	I	**WRITE FOR PORT B:** This pin is the write memory request command input for port B. This input also directly accepts the $\overline{S0}$ status line from Intel processors.
$\overline{PEB}$	63	I	**PORT ENABLE FOR PORT B:** This pin serves to enable a RAM cycle request for port B. It is generally decoded from the port address.
PCTLB	64	I	**PORT CONTROL FOR PORT B:** This pin is sampled on the falling edge of RESET. It configures port B to accept command inputs or processor status inputs. If low after RESET, the 8207 is programmed to accept command or iAPX 286 status inputs or Multibus commands. If high after RESET, the 8207 is programmed to accept status inputs from iAPX 86 or iAPX 186 processors. The $\overline{S2}$ status line should be connected to this input if programmed to accept iAPX 86 or iAPX 186 status inputs. When programmed to accept commands or iAPX 286 status, it should be tied low or it may be used as a Multibus-compatible inhibit signal.
$\overline{RDA}$	65	I	**READ FOR PORT A:** This pin is the read memory request command input for port A. This input also directly accepts the $\overline{S1}$ status line from Intel processors.
$\overline{WRA}$	66	I	**WRITE FOR PORT A:** This pin is the write memory request command input for port A. This input also directly accepts the $\overline{S0}$ status line from Intel processors.
$\overline{PEA}$	67	I	**PORT ENABLE FOR PORT A:** This pin serves to enable a RAM cycle request for port A. It is generally decoded from the port address.
PCTLA	68	I	**PORT CONTROL FOR PORT A:** This pin is sampled on the falling edge of RESET. It configures port A to accept command inputs or processor status inputs. If low after RESET, the 8207 is programmed to accept command or iAPX 286 status inputs or Multibus commands. If high after RESET, the 8207 is programmed to accept status inputs from iAPX 86 or iAPX 186 processors. The $\overline{S2}$ status line should be connected to this input if programmed to accept iAPX 86 or iAPX 186 status inputs. When programmed to accept commands or iAPX 286 status, it should be tied low or it may be connected to INHIBIT when operating with Multibus.

GENERAL DESCRIPTION

The Intel 8207 Advanced Dynamic RAM Controller (ADRC) is a microcomputer peripheral device which provides the necessary signals to address, refresh and directly drive 16K, 64K and 256K dynamic RAMs. This controller also provides the necessary arbitration circuitry to support dual-port access of the dynamic RAM array.

The ADRC supports several microprocessor interface options including synchronous and asynchronous connection to iAPX 86, iAPX 88, iAPX 186, iAPX 286 and Multibus.

This device may be used with the 8206 Error Detection and Correction Unit (EDCU). When used with the 8206, the 8207 is programmed in the Error Checking and Correction (ECC) mode. In this mode, the 8207 provides all the necessary control signals for the 8206 to perform memory initialization and transparent error scrubbing during refresh.

FUNCTIONAL DESCRIPTION

Processor Interface

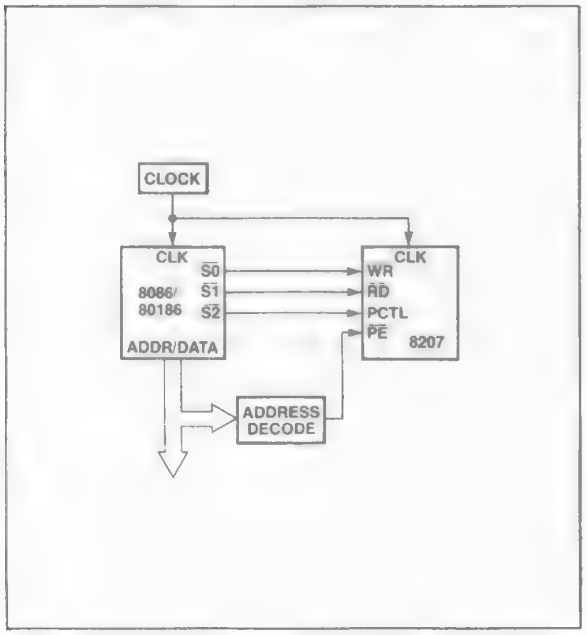
The 8207 has control circuitry for two ports each capable of supporting one of several possible bus structures. The ports are independently configurable allowing the dynamic RAM to serve as an interface between two different bus structures.

Each port of the 8207 may be programmed to run synchronous or asynchronous to the processor clock. (See Synchronous/Asynchronous Mode) The 8207 has been optimized to run synchronously with Intel's iAPX 86, iAPX 88, iAPX 186 and iAPX 286. When the 8207 is programmed to run in asynchronous mode, the 8207 inserts the necessary synchronization circuitry for the $\overline{RD}$, $\overline{WR}$, $\overline{PE}$, and PCTL inputs.

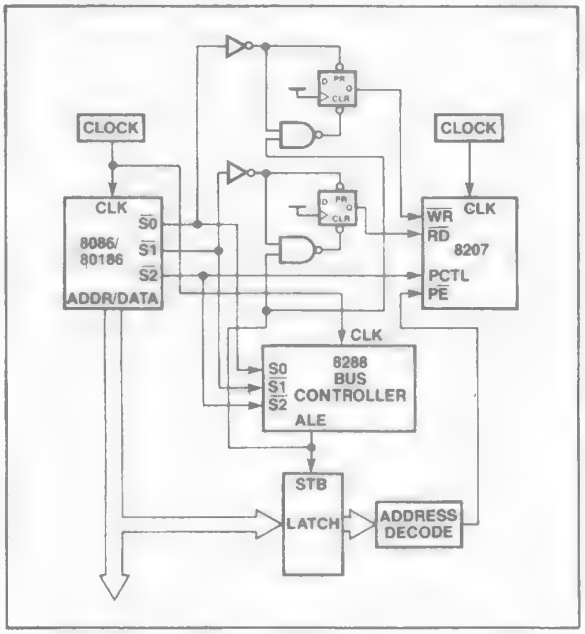
The 8207 can also decode the status lines directly from the iAPX 86, iAPX 88, iAPX 186 and the iAPX 286 or can be programmed to receive read or write Multibus commands or commands from a bus controller. (See Status/Command Mode)

The 8207 may be programmed to accept the clock of the iAPX 86, 88, 186, or 286. The 8207 adjusts its internal timing to allow for the different clock frequencies of these microprocessors. (See Microprocessor Clock Frequency Option)

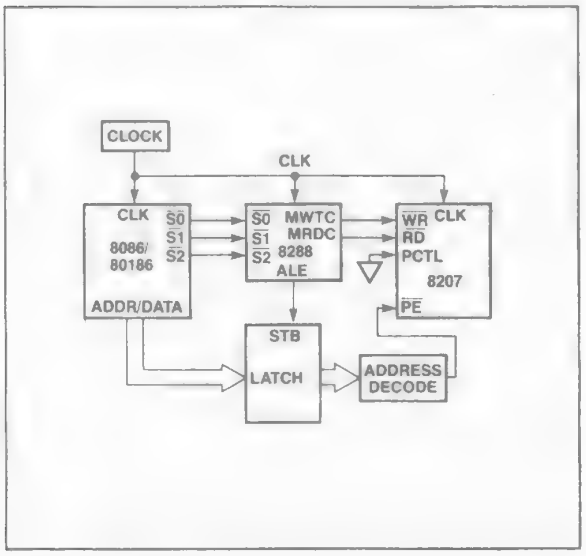
Figure 2 shows the different processor interfaces to the 8207 using the synchronous or asynchronous mode and status or command interface.



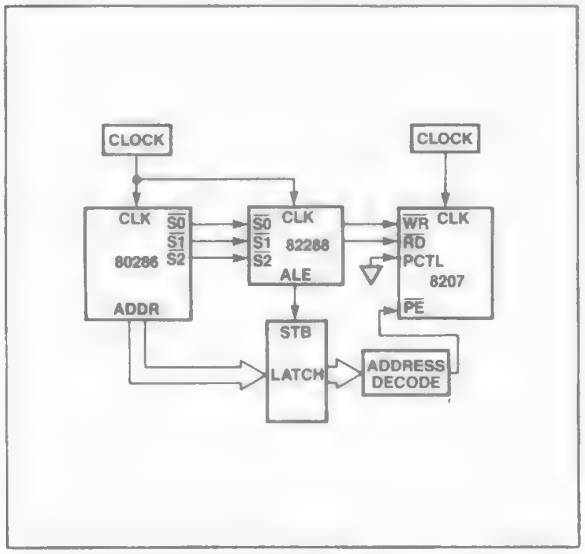
Slow-Cycle Synchronous-Status Interface



Slow-Cycle Asynchronous-Status Interface



Slow-Cycle Synchronous-Command Interface



Slow-Cycle Asynchronous-Command Interface

Figure 2A. Slow-cycle Port Interfaces Supported by the 8207

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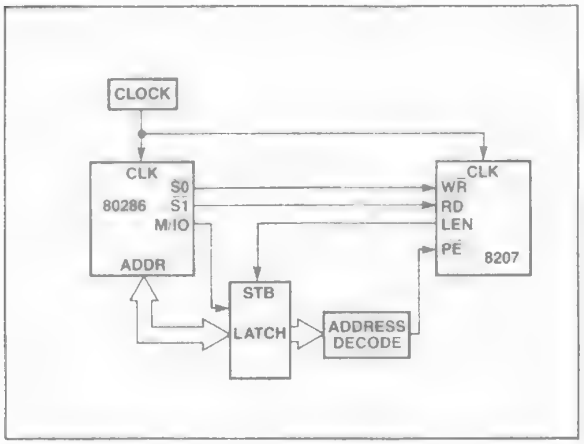
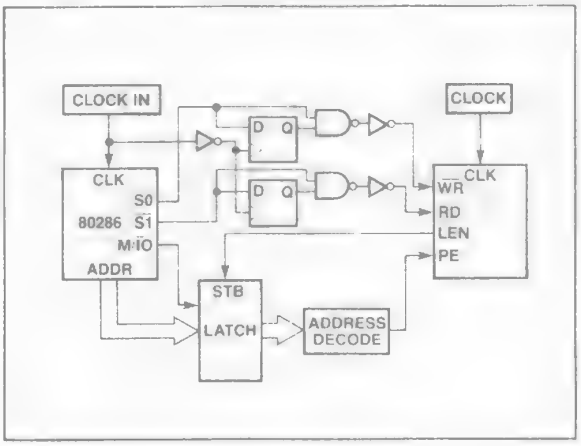
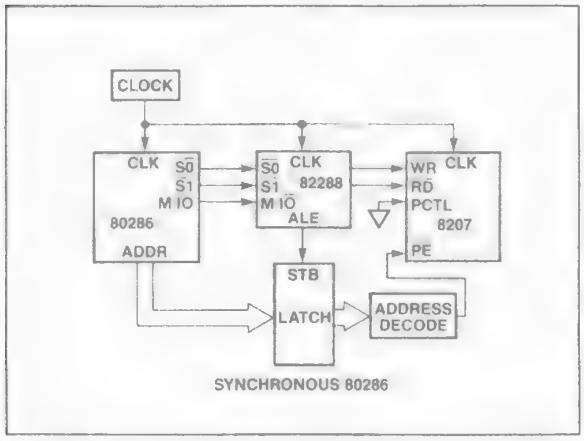


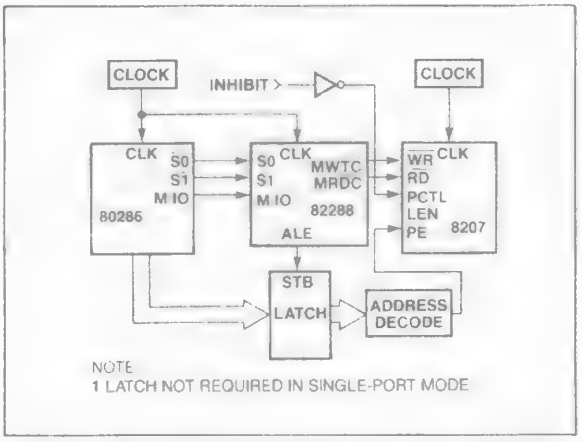
Fast-Cycle Synchronous-Status Interface



Fast-Cycle Asynchronous-Status Interface



Fast-Cycle Synchronous-Command Interface



Fast-Cycle Asynchronous-Command Interface

Figure 2B. Fast-cycle Port Interfaces Supported by the 8207

Dual-Port Operation

The 8207 provides for two-port operation. Two independent processors may access memory controlled by the 8207. The 8207 arbitrates between each of the processor requests and directs data to or from the appropriate port. Selection is done on a priority concept that reassigns priorities based upon past history. Processor requests are internally queued.

Figure 3 shows a dual-port configuration with two iAPX 86 systems interfacing to dynamic RAM. One of the processor systems is interfaced synchronously using the status interface and the other is interfaced asynchronously also using the status interface.

Dynamic RAM Interface

The 8207 is capable of addressing 16K, 64K and 256K dynamic RAMs. Figure 4 shows the connection of the processor address bus to the 8207 using the different RAMs. The 8207 directly supports the 2118 RAM family or any RAM with similar timing requirements and responses including the Intel 2164A RAM.

The 8207 divides memory into four banks, each bank having its own Row ($\overline{RAS}$) and Column ($\overline{CAS}$) Address Strobe pair. This organization permits RAM cycle interleaving and permits error scrubbing during ECC refresh cycles. RAM cycle interleaving overlaps the start of the next RAM cycle with the RAM Precharge period of the previous cycle. Hiding the

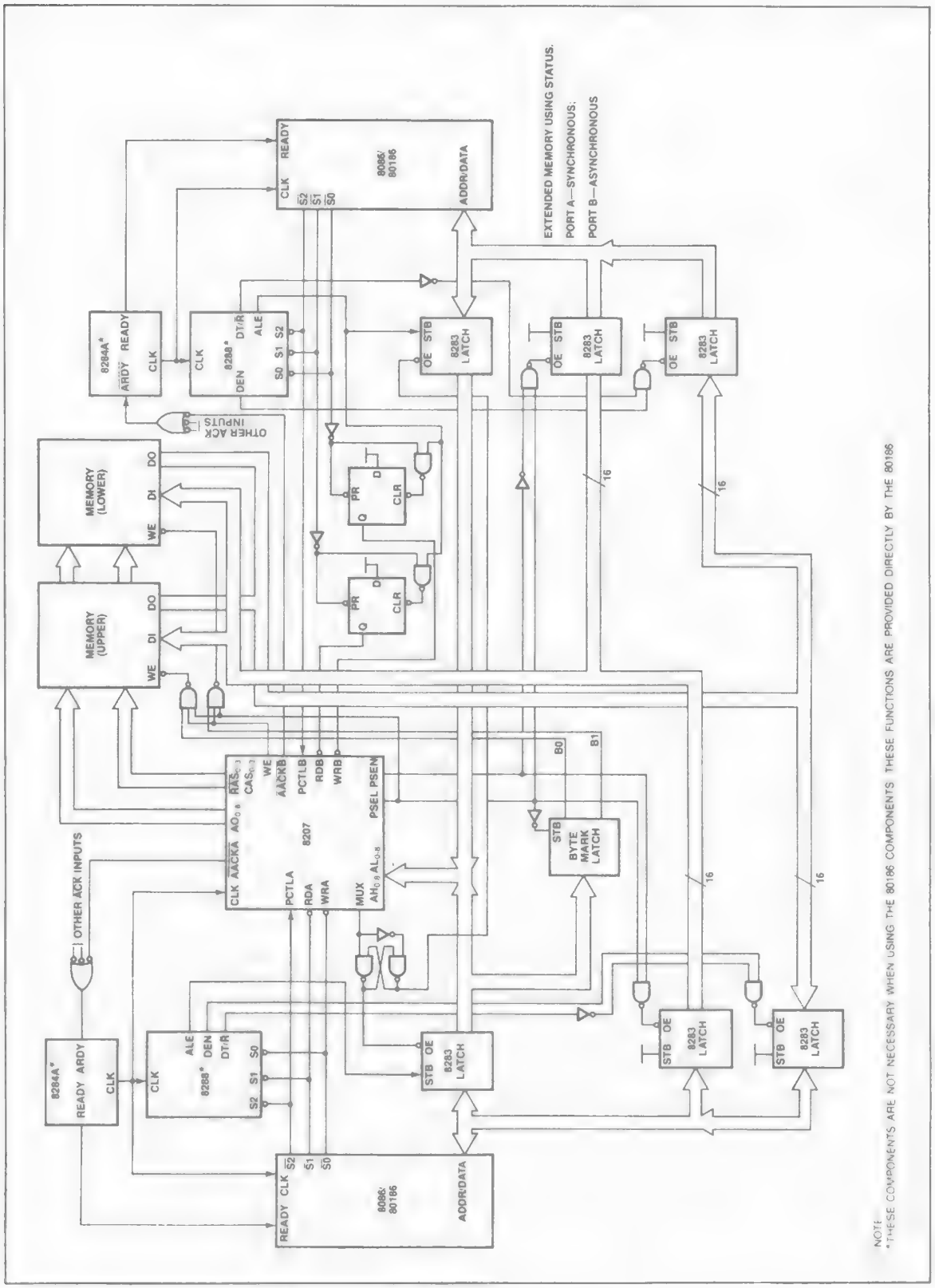
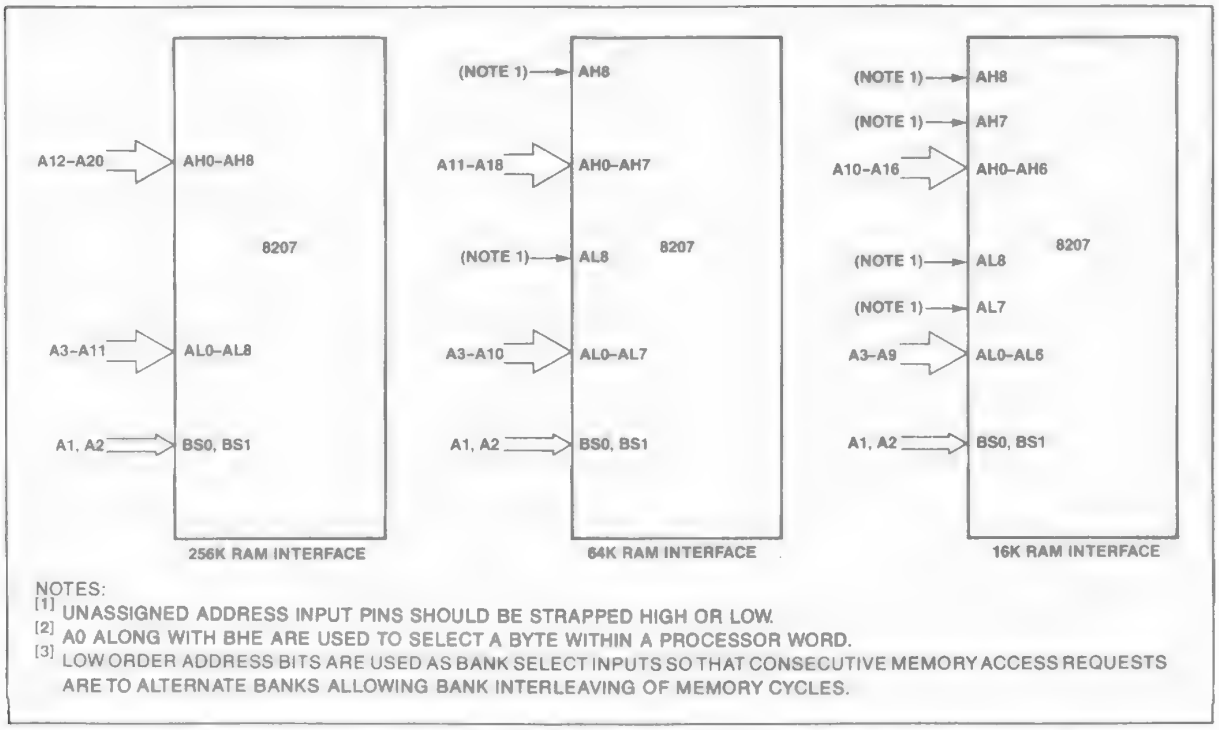


Figure 3. 8086/80186 Dual Port System



NOTES:
[1] UNASSIGNED ADDRESS INPUT PINS SHOULD BE STRAPPED HIGH OR LOW.
[2] A0 ALONG WITH BHE ARE USED TO SELECT A BYTE WITHIN A PROCESSOR WORD.
[3] LOW ORDER ADDRESS BITS ARE USED AS BANK SELECT INPUTS SO THAT CONSECUTIVE MEMORY ACCESS REQUESTS ARE TO ALTERNATE BANKS ALLOWING BANK INTERLEAVING OF MEMORY CYCLES.

Figure 4. Processor Address Interface to the 8207 Using 16K, 64K, and 256K RAMS

precharge period of one RAM cycle behind the data access period of the next RAM cycle optimizes memory bandwidth and is effective as long as successive RAM cycles occur in alternate banks.

Successive data access to the same bank will cause the 8207 to wait for the precharge time of the previous RAM cycle.

If not all RAM banks are occupied, the 8207 reassigns the $\overline{RAS}$ and $\overline{CAS}$ strobes to allow using wider data words without increasing the loading on the $\overline{RAS}$ and $\overline{CAS}$ drivers. Table 2 shows the bank selection decoding and the word expansion, including $\overline{RAS}$ and $\overline{CAS}$ assignments. For example, if only two RAM banks are occupied, then two $\overline{RAS}$ and two $\overline{CAS}$ strobes are activated per bank.

The 8207 can interface to fast (e.g., 2118-10) or slow (e.g., 2118-15) RAMs. The 8207 adjusts and optimizes internal timings for either the fast or slow RAMs as programmed. (See RAM Speed Option)

Memory Initialization

After programming, the 8207 performs eight RAM "warm-up" cycles to prepare the dynamic RAM for proper device operation and, if configured for operation with error correction, the 8207 and 8206 EDCU will proceed to initialize all of memory (memory is written with zeros with corresponding check bits).

Table 2. Bank Selection Decoding and Word Expansion

Program Bits		Bank Input		
RB1	RB0	B1	B0	RAS/CAS Pair Allocation
0	0	0	0	RAS_{0-3}, CAS_{0-3} to Bank 0
0	0	0	1	Bank 1 unoccupied
0	0	1	0	Bank 2 unoccupied
0	0	1	1	Bank 3 unoccupied
0	1	0	0	$RAS_{0,1}$, $CAS_{0,1}$ to Bank 0
0	1	0	1	$RAS_{2,3}$, $CAS_{2,3}$ to Bank 1
0	1	1	0	Bank 2 unoccupied
0	1	1	1	Bank 3 unoccupied
1	0	0	0	RAS_0, CAS_0 to Bank 0
1	0	0	1	RAS_1, CAS_1 to Bank 1
1	0	1	0	RAS_2, CAS_2 to Bank 2
1	0	1	1	Bank 3 unoccupied
1	1	0	0	RAS_0, CAS_0 to Bank 0
1	1	0	1	RAS_1, CAS_1 to Bank 1
1	1	1	0	RAS_2, CAS_2 to Bank 2
1	1	1	1	RAS_3, CAS_3 to Bank 3

Because the time to initialize memory is fairly long, the 8207 may be programmed to skip initialization in ECC mode. The time required to initialize all of memory is dependent on the clock cycle time to the 8207 and can be calculated by the following equation:

eq.1 $T_{INIT} = (2^{23})\ T_{CY}$

if T_{CY} = 125 ns then $T_{INIT} \approx 1$ sec.

8206 ECC Interface

For operation with Error Checking and Correction (ECC), the 8207 adjusts its internal timing and changes some pin functions to optimize performance and provide a clean dual-port memory interface between the 8206 EDCU and memory. The 8207 directly supports a master-only (16-bit word plus 6 check bits) system. Under extended operation and reduced clock frequency, the 8207 will support any ECC master-slave configuration up to 80 data bits, which is the maximum set by the 8206 EDCU. (See Extend Option)

Correctable errors detected during memory read cycles are corrected immediately and then written back into memory.

In a synchronous bus environment, ECC system performance has been optimized to enhance processor throughput, while in an asynchronous bus environment (the Multibus), ECC performance has been optimized to get valid data onto the bus as quickly as possible. Performance optimization, processor throughput or quick data access may be selected via the Transfer Acknowledge Option.

The main difference between the two ECC implementations is that, when optimized for processor throughput, RAM data is always corrected and an advanced transfer acknowledge is issued at a point when, by knowing the processor characteristics, data is guaranteed to be valid by the time the processor needs it.

When optimized for quick data access, (valid for Multibus) the 8206 is configured in the uncorrecting mode where the delay associated with error correction circuitry is transparent, and a transfer acknowledge is issued as soon as valid data is known to exist. If the $\overline{ERROR}$ flag is activated, then the transfer acknowledge is delayed until after the 8207 has instructed the 8206 to correct the data and the corrected data becomes available on the bus. Figure 5 illustrates a dual-port ECC system.

Figure 6 illustrates the interface required to drive the $\overline{CRCT}$ pin of the 8206, in the case that one port (PORT A) receives an advanced acknowledge (not Multibus-compatible), while the other port (PORT B) receives $\overline{XACK}$ (which is Multibus-compatible).

Error Scrubbing

The 8207/8206 performs error correction during refresh cycles (error scrubbing). Since the 8207 must refresh RAM, performing error scrubbing during refresh allows it to be accomplished without additional performance penalties.

Upon detection of a correctable error during refresh, the RAM refresh cycle is lengthened slightly to permit the 8206 to correct the error and for the corrected word to be rewritten into memory. Uncorrectable errors detected during scrubbing are ignored.

Refresh

The 8207 provides an internal refresh interval counter and a refresh address counter to allow the 8207 to refresh memory. The 8207 will refresh 128 rows every 2 milliseconds or 256 rows every 4 milliseconds, which allows all RAM refresh options to be supported. In addition, there exists the ability to refresh 256 row address locations every 2 milliseconds via the Refresh Period programming option.

The 8207 may be programmed for any of five different refresh options: Internal refresh only, External refresh with failsafe protection, External refresh without failsafe protection, Burst Refresh mode, or no refresh. (See Refresh Options)

It is possible to decrease the refresh time interval by 10%, 20% or 30%. This option allows the 8207 to compensate for reduced clock frequencies. Note that an additional 5% interval shortening is built-in in all refresh interval options to compensate for clock variations and non-immediate response to the internally generated refresh request. (See Refresh Period Options)

External Refresh Requests after RESET

External refresh requests are not recognized by the 8207 until after it is finished programming and preparing memory for access. Memory preparation includes 8 RAM cycles to prepare and ensure proper

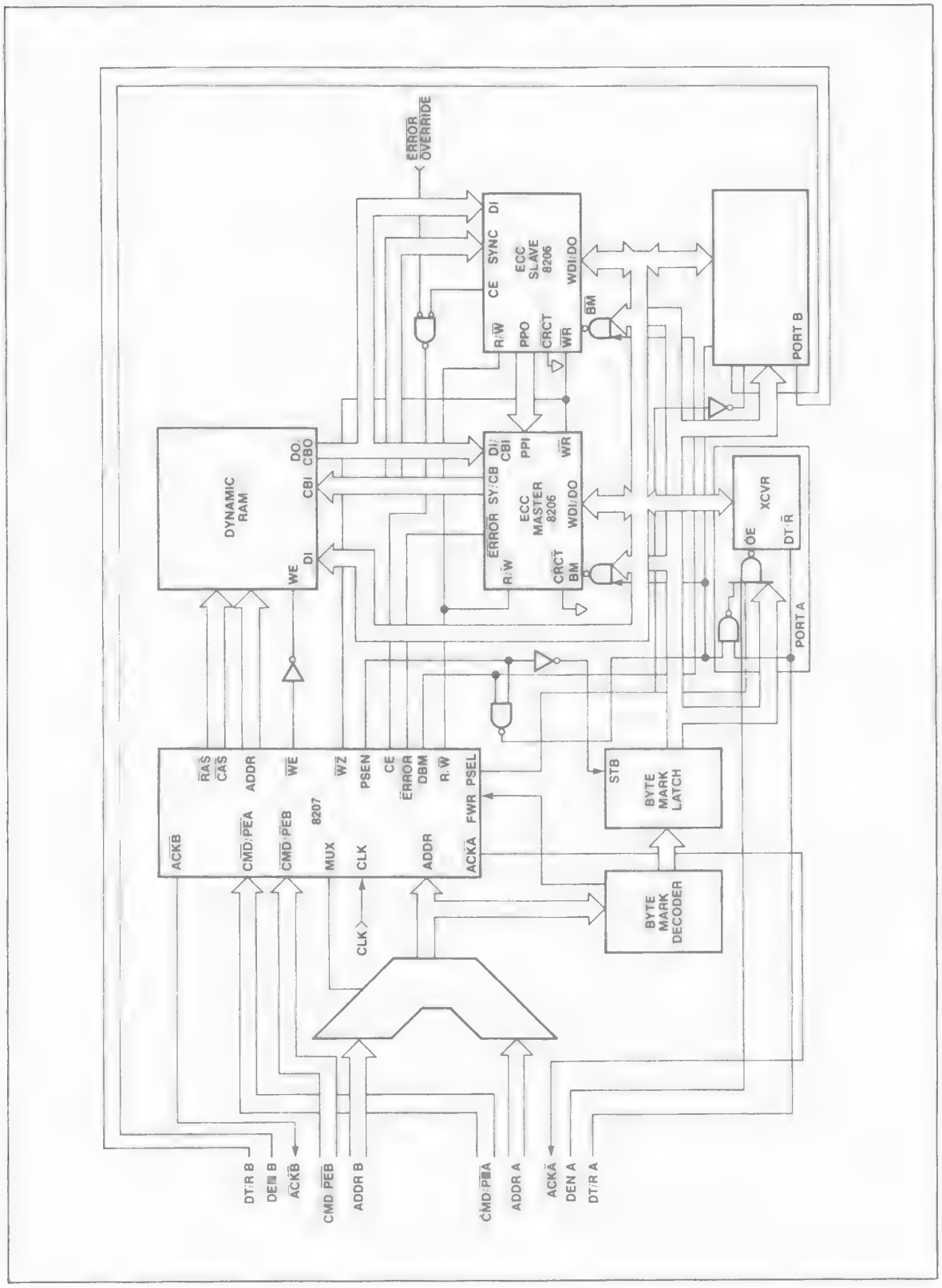


Figure 5. Two-Port ECC Implementation Using the 8207 and the 8206

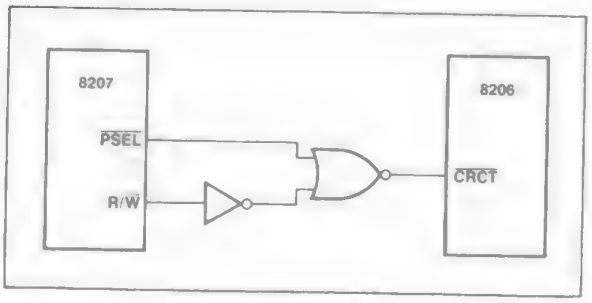


Figure 6. Interface to 8206 $\overline{CRCT}$ Input When Port A Receives $\overline{AACK}$ and Port B Receives $\overline{XACK}$

dynamic RAM operation, and memory initialization if error correction is used. Many dynamic RAMs require this warm-up period for proper operation. The time it takes for the 8207 to recognize a request is shown below.

eq. 2 Non-ECC Systems: $T_{RESP} = T_{PROG} + T_{PREP}$

eq. 3 where: $T_{PROG} = (66)(T_{CY})$ which is programming time

eq. 4 $T_{PREP} = (8)(32)(T_{CY})$ which is the RAM warm-up time

if $T_{CY} = 125$ ns then $T_{RESP} \approx 41$ us

eq. 5 ECC Systems: $T_{RESP} = T_{PROG} + T_{PREP} + T_{INIT}$

if $T_{CY} = 125$ ns then $T_{RESP} \approx 1$ sec

RESET

RESET is an asynchronous input, the falling edge of which is used by the 20 to directly sample the logic levels of the PCTLA, PCTLB, RFRQ, and PDI inputs. The internally synchronized falling edge of RESET is used to begin programming operations (shifting in the contents of the external shift register into the PDI input).

Until programming is complete the 8207 registers but does not respond to command or status inputs. A simple means of preventing commands or status from occurring during this period is to differentiate the system reset pulse to obtain a smaller reset pulse for the 8207. The total time of the reset pulse and the 8207 programming time must be less than the time before the first command in systems that alter the default port synchronization programming bits (default is Port A synchronous, Port B asynchronous). Differentiated reset is unnecessary when the default port synchronization programming is used.

The differentiated reset pulse would be shorter than the system reset pulse by at least the programming period required by the 8207. The differentiated reset pulse first resets the 8207, and system reset would reset the rest of the system. While the rest of the system is still in reset, the 8207 completes its programming. Figure 7 illustrates a circuit to accomplish this task.

Within four clocks after RESET goes active, all the 8207 outputs will go high, except for PSEN, WE, and AO0-8, which will go low.

OPERATIONAL DESCRIPTION

Programming the 8207

The 8207 is programmed after reset. On the falling edge of RESET, the logic states of several input pins are latched internally. The falling edge of RESET actually performs the latching, which means that the logic levels on these inputs must be stable prior to that time. The inputs whose logic levels are latched at the end of reset are the PCTLA, PCTLB, REFRQ, and PDI pins. Figure 8 shows the necessary timing for programming the 8207.

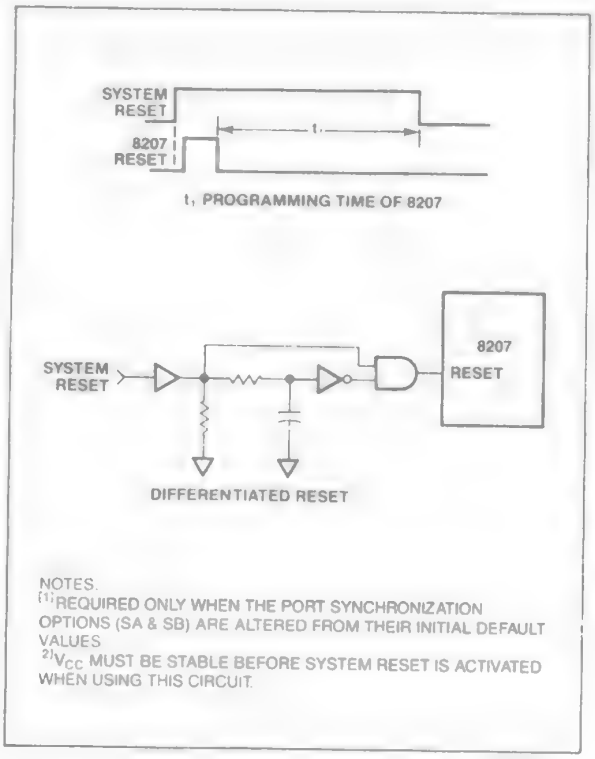
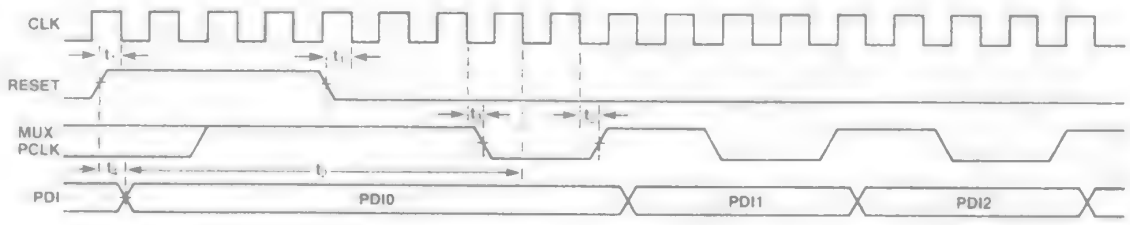


Figure 7. 8207 Differentiated Reset Circuit



NOTES
t_1—RESET IS AN ASYNCHRONOUS INPUT. IF RESET OCCURS BEFORE t_1, THEN IT IS GUARANTEED TO BE RECOGNIZED
t_2—MINIMUM PDI VALID TIME PRIOR TO CLOCK EDGE THAT RECOGNIZES END OF RESET.
t_3—MUX PCLK DELAY
t_4—ASYNCHRONOUS LOAD DATA PROPAGATION DELAY.

Figure 8. Timing Illustrating External Shift Register Requirements for Programming the 8207

Status/Command Mode

The two processor ports of the 8207 are configured by the states of the PCTLA and PCTLB pins. Which interface is selected depends on the state of the individual port's PCTL pin at the end of reset. If PCTL is high at the end of the reset, the 8086 Status interface is selected; if it is low, then the Command interface is selected.

The status lines of the 80286 are similar in code and timing to the Multibus command lines, while the status code and timing of the 8086 and 8088 are identical to those of the 80186 (ignoring the differences in clock duty cycle). Thus there exists two interface configurations, one for the 80286 status or Multibus memory commands, which is called the Command interface, and one for 8086, 8088 or 80186 status, called the 8086 Status interface. The Command interface can also directly interface to the command lines of the bus controllers for the 8086, 8088, 80186 and the 80286.

The 8086 Status interface allows direct decoding of the status of the iAPX 86, iAPX 88, and the iAPX 186. Table 3 shows how the status lines are decoded. While in the Command mode the iAPX 286 status can be directly decoded. Microprocessor bus controller read or write commands or Multibus commands can also be directed to the 8207 when in Command mode.

Refresh Options

Immediately after system reset, the state of the REFRQ input pin is examined. If REFRQ is high, the 8207 provides the user with the choice between self-refresh or user-generated refresh with failsafe protection. Failsafe protection guarantees that if the

Table 3A. Status Coding of 8086, 80186 and 80286

Status Code			Function	
$\overline{S2}$	$\overline{S1}$	$\overline{S0}$	8086/80186	80286
0	0	0	INTERRUPT	INTERRUPT
0	0	1	I/O READ	I/O READ
0	1	0	I/O WRITE	I/O WRITE
0	1	1	HALT	IDLE
1	0	0	INSTRUCTION FETCH	HALT
1	0	1	MEMORY READ	MEMORY READ
1	1	0	MEMORY WRITE	MEMORY WRITE
1	1	1	IDLE	IDLE

Table 3B. 8207 Response

8207 Command			Function	
PCTL	$\overline{RD}$	$\overline{WR}$	8086 Status Interface	Command Interface
0	0	0	IGNORE	IGNORE
0	0	1	IGNORE	READ
0	1	0	IGNORE	WRITE
0	1	1	IGNORE	IGNORE
1	0	0	READ	IGNORE
1	0	1	READ	INHIBIT
1	1	0	WRITE	INHIBIT
1	1	1	IGNORE	IGNORE

user does not come back with another refresh request before the internal refresh interval counter times out, a refresh request will be automatically generated. If the REFRQ pin is low immediately after a reset, then the user has the choice of a single external refresh cycle without failsafe, burst refresh or no refresh.

Internal Refresh Only

For the 8207 to generate internal refresh requests, it is necessary only to strap the REFRQ input pin high.

External Refresh with Failsafe

To allow user-generated refresh requests with failsafe protection, it is necessary to hold the REFRQ input high until after reset. Thereafter, a low-to-high transition on this input causes a refresh request to be generated and the internal refresh interval counter to be reset. A high-to-low transition has no effect on the 8207. A refresh request is not recognized until a previous request has been serviced.

External Refresh without Failsafe

To generate single external refresh requests without failsafe protection, it is necessary to hold REFRQ low until after reset. Thereafter, bringing REFRQ high for one clock period causes a refresh request to be generated. A refresh request is not recognized until a previous request has been serviced.

Burst Refresh

Burst refresh is implemented through the same procedure as a single external refresh without failsafe (i.e., REFRQ is kept low until after reset). Thereafter, bringing REFRQ high for a least two clock periods causes a burst of 128 row address locations to be refreshed.

In ECC-configured systems, 128 locations are scrubbed. A burst refresh request is not recognized until a previous request has been serviced.

No Refresh

It is necessary to hold REFRQ low until after reset. This is the same as programming External Refresh without Failsafe. No refresh is accomplished by keeping REFRQ low.

Option Program Data Word

The program data word consists of 16 program data bits, PD0–PD15. If the first program data bit PD0 is set to logic 1, the 8207 is configured to support ECC. If it is logic 0, the 8207 is configured to support a non-ECC system. The remaining bits, PD1–PD15, may then be programmed to optimize a selected configuration. Figures 9 and 10 show the Program word for non-ECC and ECC operation.

Using an External Shift Register

The 8207 may be configured to use an external shift register with asynchronous load capability such as a 74LS165. The reset pulse serves to parallel load the shift register and the 8207 supplies the clocking signal to shift the data in. Figure 11 shows a sample circuit diagram of an external shift register circuit. Serial data is shifted into the 8207 via the PDI pin (57), and clock is provided by the MUX/PCLK pin (12), which generates a total of 16 clock pulses. After programming is complete, data appearing at the input of the PDI pin is ignored. MUX/PCLK is a dual-function pin. During programming, it serves to clock the external shift register, and after programming is completed, it reverts to a MUX control pin. As the pin changes state to select different port addresses, it continues to clock the shift register. This does not present a problem because data at the PDI pin is ignored after programming. Figure 8 illustrates the timing requirements of the shift register circuitry.

ECC Mode (ECC Program Bit)

The state of PDI (Program Data In) pin at reset determines whether the system is an ECC or non-ECC configuration. It is used internally by the 8207 to begin configuring timing circuits, even before programming is completely finished. The 8207 then begins programming the rest of the options.

Default Programming Options

After reset, the 8207 serially shifts in a program data word via the PDI pin. This pin may be strapped either high or low, or connected to an external shift register. Strapping PDI high causes the 8207 to default to a particular system configuration with error correction, and strapping it low causes the 8207 to default to a particular system configuration without error correction. Table 4 shows the default configurations.

PD15							PD8	PD7							PD0
0	0	TM 1	PPR	FFS	EXT	PLS	CI0	CI1	RB1	RB0	RFS	CFS	SB	SA	0

PROGRAM DATA BIT	NAME	POLARITY/FUNCTION
PD0	ECC	ECC = 0 FOR NON-ECC MODE
PD1	SA	SA = 0 PORT A IS SYNCHRONOUS SA = 1 PORT A IS ASYNCHRONOUS
PD2	SB	SB = 0 PORT B IS ASYNCHRONOUS SB = 1 PORT B IS SYNCHRONOUS
PD3	CFS	CFS = 0 FAST-CYCLE iAPX 286 MODE CFS = 1 SLOW-CYCLE iAPX 86 MODE
PD4	RFS	RFS = 0 FAST RAM RFS = 1 SLOW RAM
PD5 PD6	RB0 RB1	RAM BANK OCCUPANCY SEE TABLE 2
PD7	CI1	COUNT INTERVAL BIT 1; SEE TABLE 6
PD8	CI0	COUNT INTERVAL BIT 0; SEE TABLE 6
PD9	PLS	PLS = 0 LONG REFRESH PERIOD PLS = 1 SHORT REFRESH PERIOD
PD10	EXT EXT	EXT = 0 NOT EXTENDED EXT = 1 EXTENDED
PD11	FFS	FFS = 0 FAST CPU FREQUENCY FFS = 1 SLOW CPU FREQUENCY
PD12	PPR	PPR = 0 MOST RECENTLY USED PORT PRIORITY PPR = 1 PORT A PREFERRED PRIORITY
PD13	TM1	TM1 = 0 TEST MODE 1 OFF TM1 = 1 TEST MODE 1 ENABLED
PD14	0	RESERVED MUST BE ZERO
PD15	0	RESERVED MUST BE ZERO

Figure 9. Non-ECC Mode Program Data Word

PD15							PD8	PD7							PD0
TM2	RB1	RB0	PPR	FFS	EXT	PLS	CI0	CI1	XB	XA	RFS	CFS	SB	SA	1

PROGRAM DATA BIT	NAME	POLARITY/FUNCTION
PD0	ECC	ECC = 1 ECC MODE
PD1	SA	SA = 0 PORT A ASYNCHRONOUS SA = 1 PORT A SYNCHRONOUS
PD2	SB	SB = 0 PORT B SYNCHRONOUS SB = 1 PORT B ASYNCHRONOUS
PD3	CFS	CFS = 0 SLOW-CYCLE iAPX 86 MODE CFS = 1 FAST-CYCLE iAPX 286 MODE
PD4	RFS	RFS = 0 SLOW RAM RFS = 1 FAST RAM
PD5	XA	XA = 0 MULTIBUS-COMPATIBLE ACKA XA = 1 ADVANCED ACKA NOT MULTIBUS-COMPATIBLE
PD6	XB	XB = 0 ADVANCED ACKB NOT MULTIBUS COMPATIBLE XB = 1 MULTIBUS-COMPATIBLE ACKB
PD7	CI1	COUNT INTERVAL BIT 1; SEE TABLE 6
PD8	CI0	COUNT INTERVAL BIT 0; SEE TABLE 6
PD9	PLS	PLS = 0 SHORT REFRESH PERIOD PLS = 1 LONG REFRESH PERIOD
PD10	EXT	EXT = 0 MASTER AND SLAVE EDCU EXT = 1 MASTER EDCU ONLY
PD11	FFS	FFS = 0 SLOW CPU FREQUENCY FFS = 1 FAST CPU FREQUENCY
PD12	PPR	PPR = 0 PORT A PREFERRED PRIORITY PPR = 1 MOST RECENTLY USED PORT PRIORITY
PD13 PD14	RB0 RB1	RAM BANK OCCUPANCY SEE TABLE 2
PD15	TM2	TM2 = 0 TEST MODE 2 ENABLED TM2 = 1 TEST MODE 2 OFF

Figure 10. ECC Mode Program Data Word

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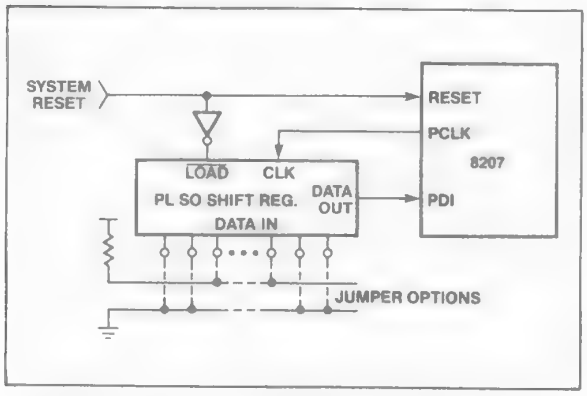

Figure 11. External Shift Register Interface

Table 4A.
Default Non-ECC Programming, PDI Pin (57) Tied to Ground.

Port A is Synchronous
Port B is Asynchronous
Fast-cycle Processor Interface
Fast RAM
Refresh Interval uses 236 clocks
128 Row refresh in 2 ms; 256 Row refresh in 4 ms
Fast Processor Clock Frequency (16 MHz)
"Most Recently Used" Priority Scheme
4 RAM banks occupied

Table 4B.
Default ECC Programming, PDI Pin (57) Tied to V_{CC}.

Port A is Synchronous
Port B is Asynchronous
Fast-cycle Processor Interface
Fast RAM
Port A has Advanced $\overline{ACKA}$ strobe (non-multibus)
Port B has Non-advance ACKB strobe (multibus)
Refresh interval uses 236 clocks
128 Row refresh in 2 ms; 256 Row refresh in 4 ms
Master EDCU only (16-bit system)
Fast Processor Clock Frequency (16 MHz)
"Most Recently Used" Priority Scheme
4 RAM banks occupied

If further system flexibility is needed, one or two external shift registers can be used to tailor the 8207 to its operating environment.

Synchronous/Asynchronous Mode (SA and SB Program Bits)

Each port of the 8207 may be independently configured to accept synchronous or asynchronous port commands ($\overline{RD}$, $\overline{WR}$, PCTL) and Port Enable ($\overline{PE}$) via the program bits SA and SB. The state of the SA and SB programming bits determine whether their associated ports are synchronous or asynchronous.

While a port may be configured with either the Status or Command interface in the synchronous mode, certain restrictions exist in the asynchronous mode. An asynchronous Command interface using the control lines of the Multibus is supported, and an asynchronous 8086 interface using the control lines of the 8086 is supported, with the use of TTL gates as illustrated in Figure 2. In the 8086 case, the TTL gates are needed to guarantee that status does not appear at the 8207 inputs too much before address, so that a cycle would start before address was valid.

Microprocessor Clock Frequency Option (CFS and FFS Program Bits)

The 8207 can be programmed to interface with slow-cycle microprocessors like the 8086, 8088, and 80186 or fast-cycle microprocessors like the 80286. The CFS bit configures the microprocessor interface to accept slow or fast cycle signals from either microprocessor group.

This option is used to select the speed of the microprocessor clock. Table 5 shows the various microprocessor clock frequency options that can be programmed.

Table 5.
Microprocessor Clock Frequency Options

Program Bits		Processor	Clock Frequency
CFS	FFS		
0	0	iAPX 86, 88, 186	5 MHz
0	1	iAPX 86, 88, 186	8 MHz
1	0	iAPX 286	10 MHz
1	1	iAPX 286	16 MHz

The external clock frequency must be programmed so that the failsafe refresh repetition circuitry can adjust its internal timing accordingly to produce a refresh request as programmed.

RAM Speed Option (RFS Program Bit)

The RAM Speed programming option determines whether RAM timing will be optimized for a fast or slow RAM. Whether a RAM is fast or slow is measured relative to the 2118-10 (Fast) or the 2118-15 (Slow) RAM specifications.

Refresh Period Options (CI0, CI1, and PLS Program Bits)

The 8207 refreshes with either 128 rows every 2 milliseconds or 256 rows every 4 milliseconds. This translates to one refresh cycle being executed approximately once every 15.6 microseconds. This rate can be changed to 256 rows every 2 milliseconds or a refresh approximately once every 7.8 microseconds via the Period Long/Short, program bit PLS, programming option. The 7.8 microsecond refresh request rate is intended for those RAMs, 64K and above, which may require a faster refresh rate.

In addition to PLS program option, two other programming bits for refresh exist: Count Interval 0 (CI0) and Count Interval 1 (CI1). These two programming bits allow the rate at which refresh requests are generated to be increased in order to permit refresh requests to be generated close to the same 15.6 or 7.8 microsecond period when the 8207 is operating at reduced frequencies. The interval between refreshes is decreased by 0%, 10%, 20%, or 30% as a function of how the count interval bits are programmed. A 5% guardband is built-in to allow for any clock frequency variations. Table 6 shows the refresh period options available.

The numbers tabulated under Count Interval represent the number of clock periods between internal refresh requests. The percentages in parentheses represent the decrease in interval between refresh requests. Note that all intervals have a built-in 5% (approximately) safety factor to compensate for minor clock frequency deviations and non-immediate response to internal refresh requests.

Extend Option (EXT Program Bit)

The Extend option lengthens the memory cycle to allow longer access time which may be required by the system. Extend alters the RAM timing to compensate for increased loading on the Row and Column Address Strobes, and in the multiplexed Address Out lines.

Port Priority Option and Arbitration (PPR Program Bit)

The 8207 has to internally arbitrate among three ports: Port A, Port B and Port C—the refresh port. Port C is an internal port dedicated to servicing refresh requests, whether they are generated internally by the refresh inverval counter, or externally by the user. Two arbitration approaches are available via

Table 6. Refresh Count Interval Table

Freq. (MHz)	Ref. Period (μS)	CFS	PLS	FFS	Count Interval CI1, CI0 (8207 Clock Periods)			
					00 (0%)	01 (10%)	10 (20%)	11 (30%)
16	15.6	1	1	1	236	212	188	164
	7.8	1	0	1	118	106	94	82
10	15.6	1	1	0	148	132	116	100
	7.8	1	0	0	74	66	58	50
8	15.6	0	1	1	118	106	94	82
	7.8	0	0	1	59	53	47	41
5	15.6	0	1	0	74	66	58	50
	7.8	0	0	0	37	33	29	25

the Port Priority programming option, program bit PPR. PPR determines whether the most recently used port will remain selected (PPR = 1) or whether Port A will be favored or preferred over Port B (PPR = 0).

A port is selected if the arbiter has given the selected port direct access to the timing generators. The front-end logic, which includes the arbiter, is designed to operate in parallel with the selected port. Thus a request on the selected port is serviced immediately. In contrast, an unselected port only has access to the timing generators through the front-end logic. Before a RAM cycle can start for an unselected port, that port must first become selected (i.e., the MUX output now gates that port's address into the 8207 in the case of Port A or B). Also, in order to allow its address to stabilize, a newly selected port's first RAM cycle is started by the front-end logic. Therefore, the selected port has direct access to the timing generators. What all this means is that a request on a selected port is started immediately, while a request on an unselected port is started two to three clock periods after the request, assuming that the other two ports are idle. Under normal operating conditions, this arbitration time is hidden behind the RAM cycle of the selected port so that as soon as the present cycle is over a new cycle is started. Table 7 lists the arbitration rules for both options.

Port LOCK Function

The LOCK function provides each port with the ability to obtain uninterrupted access to a critical region of memory and, thereby, to guarantee that the opposite port cannot "sneak in" and read from or write to the critical region prematurely.

Only one LOCK pin is present and is multiplexed between the two ports as follows: when MUX is high, the 8207 treats the LOCK input as originating at PORT A, while when MUX is low, the 8207 treats LOCK as originating at PORT B. When the 8207 recognizes a LOCK, the MUX output will remain pointed to the locking port until LOCK is deactivated. Refresh is not affected by LOCK and can occur during a locked memory cycle.

Table 7.
The Arbitration Rules for the Most Recently Used Port Priority and for Port A Priority Options Are As Follows:

1.	If only one port requests service, then that port—if not already selected—becomes selected.
2a.	When no service requests are pending, the last selected processor port (Port A or B) will remain selected. (Most Recently Used Port Priority Option)
2b.	When no service requests are pending, Port A is selected whether it requests service or not. (Port A Priority Option)
3.	During reset initialization only Port C, the refresh port, is selected.
4.	If no processor requests are pending after reset initialization, Port A will be selected.
5a.	If Ports A and B simultaneously(*) request service while Port C is being serviced, then the next port to be selected is the one which was not selected prior to servicing Port C. (Most Recently Used Port Priority Option)
5b.	If Ports A and B simultaneously(*) request service while Port C is selected, then the next port to be selected is Port A. (Port A Priority Option)
6.	If a port simultaneously requests service with the currently selected port, service is granted to the selected port.
7.	The MUX output remains in its last state whenever Port C is selected.
8.	If Port C and either Port A or Port B (or both) simultaneously request service, then service is granted to the requester whose port is already selected. If the selected port is not requesting service, then service is granted to Port C.
9.	If during the servicing of one port, the other port requests service before or simultaneously with the refresh port, the refresh port is selected. A new port is not selected before the presently selected port is deactivated.
10.	Activating LOCK will mask off service requests from Port B if the MUX output is high, or from Port A if the MUX output is low.

* By "simultaneous" it is meant that two or more requests are valid at the clock edge at which the internal arbiter samples them.

Dual-Port Considerations

For both ports to be operated synchronously, several conditions must be met. The processors must be the same type (Fast or Slow Cycle) as defined by Table 8 and they must have synchronized clocks. Also when processor types are mixed, even though the clocks may be in phase, one frequency may be twice that of the other. So to run both ports synchronous using the status interface, the processors must have related timings (both phase and frequency). If these conditions cannot be met, then one port must run synchronous and the other asynchronous.

Figure 3 illustrates an example of dual-port operation using the processors in the slow cycle group. Note the use of cross-coupled NAND gates at the MUX output for minimizing contention between the two latches, and the use of flip flops on the status lines of the synchonous processor for delaying the status and thereby guaranteeing RAS will not be issued, even in the worst case, until address is valid. Figure 12 shows the timing associated with Port switching.

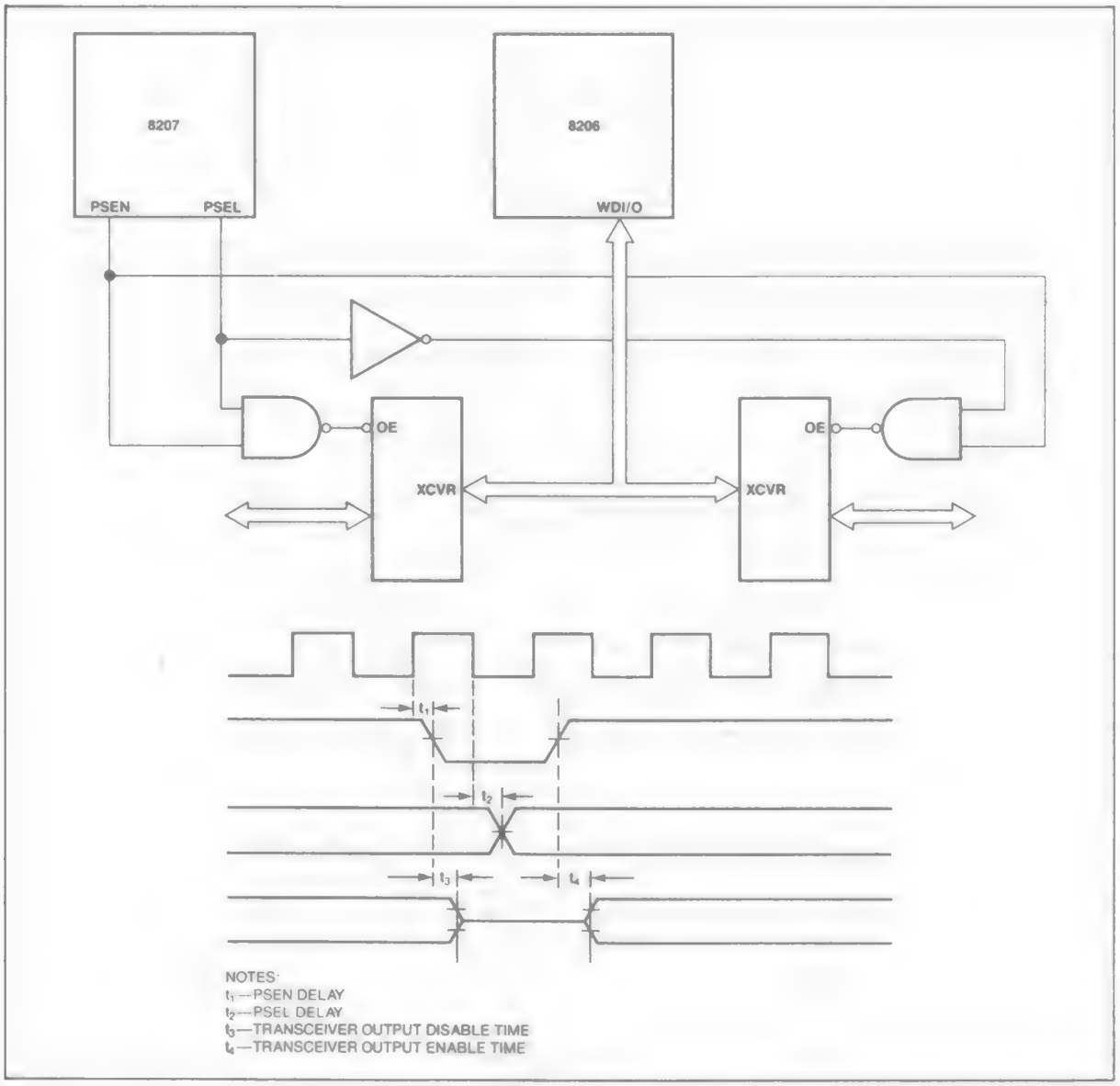

Figure 12.

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Processor Timing

Timing for the 8086, 80186, and 80286 processors is given in Figure 13. In order to run without wait states, $\overline{AACK}$ must be used and connected to the $\overline{SRDY}$ input of the appropriate bus controller. $\overline{AACK}$ is issued relative to a point within the RAM cycle and has no fixed relationship to the processor's request. The

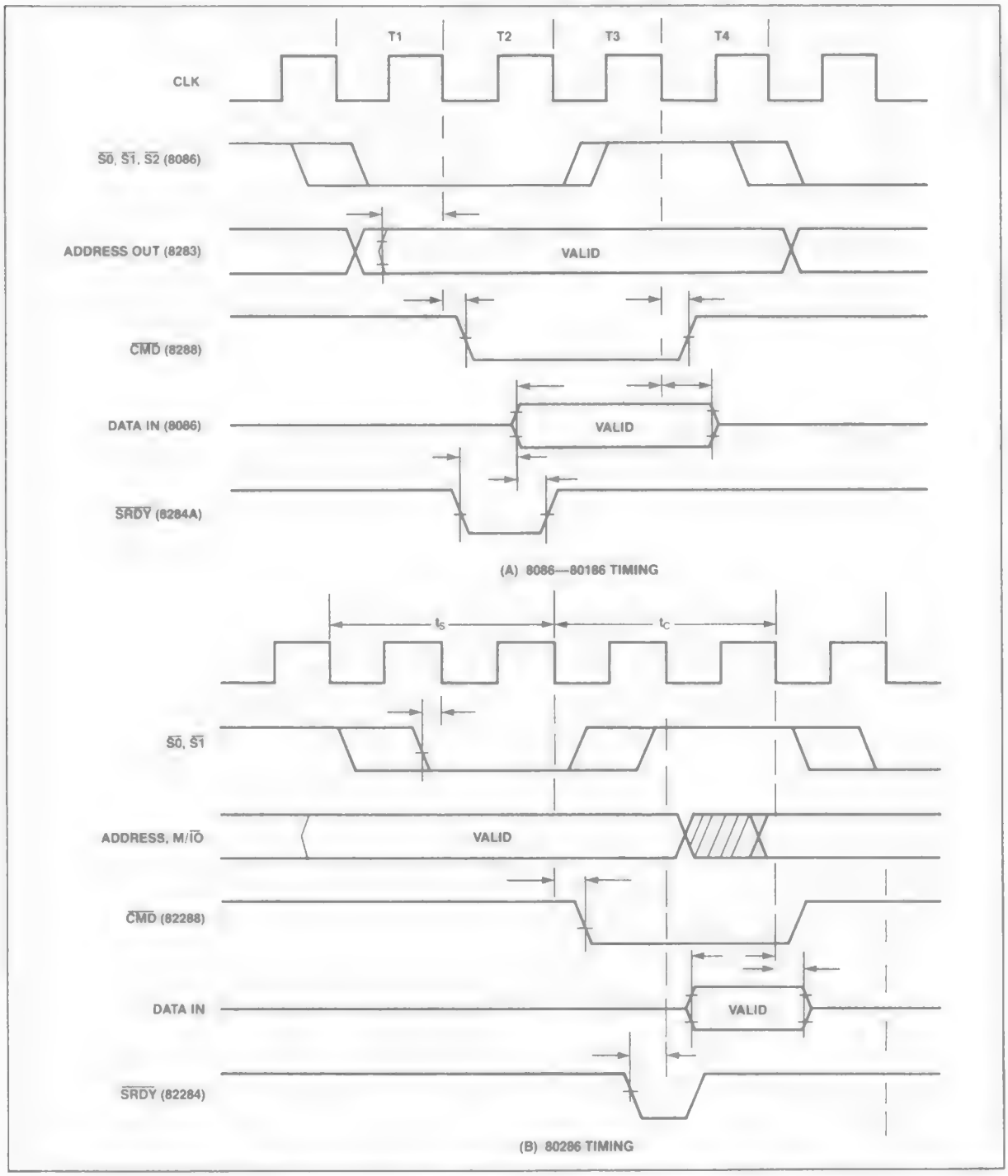

Figure 13. 8086, 80186 and 80286 Read Timing

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timing is such, however, that the processor will run without wait states, barring refresh cycles, bank precharge, and RAM accesses from the other port. In non-ECC fast cycle, fast RAM, non-extended configurations (80286), $\overline{AACK}$ is issued on the next falling edge of the clock after the edge that issues $\overline{RAS}$. In non-ECC, slow cycle, non-extended, or extended with fast RAM cycle configurations (8086, 80186), $\overline{AACK}$ is issued on the same clock cycle that issues $\overline{RAS}$. Figure 14 illustrates the timing relationship between $\overline{AACK}$, the RAM cycle, and the processor cycle for several different situations.

Port Enable ($\overline{PE}$) setup time requirements depend on whether the associated port is configured for synchronous or asynchronous operation. In synchronous operation, $\overline{PE}$ is required to be setup to the same clock edge as the status or commands. If $\overline{PE}$ is true (low), a RAM cycle is started; if not, the cycle is aborted. In asynchronous operation, $\overline{PE}$ is required to be setup to the same clock edge as the internally synchronized status or commands. Externally, this allows the internal synchronization delay to be added to the status (or command)-to-$\overline{PE}$ delay time, thus allowing for more external decode time than is available in synchronous operation. The minimum synchronization delay is the additional amount that $\overline{PE}$ must be held valid. If $\overline{PE}$ is not held valid for the maximum synchronization delay time, it is possible that $\overline{PE}$ will go invalid prior to the status or command being synchronized. In such a case the 8207 aborts the cycle. If a memory cycle intended for the 8207 is aborted, then no acknowledge ($\overline{AACK}$ or $\overline{XACK}$) is issued and the processor locks up in endless wait states. Figure 15 illustrates the status (command) timing requirements for synchronous and asynchronous systems. Figures 16 and 17 show a more detailed hook-up of the 8207 to the 8086 and 80286, respectively.

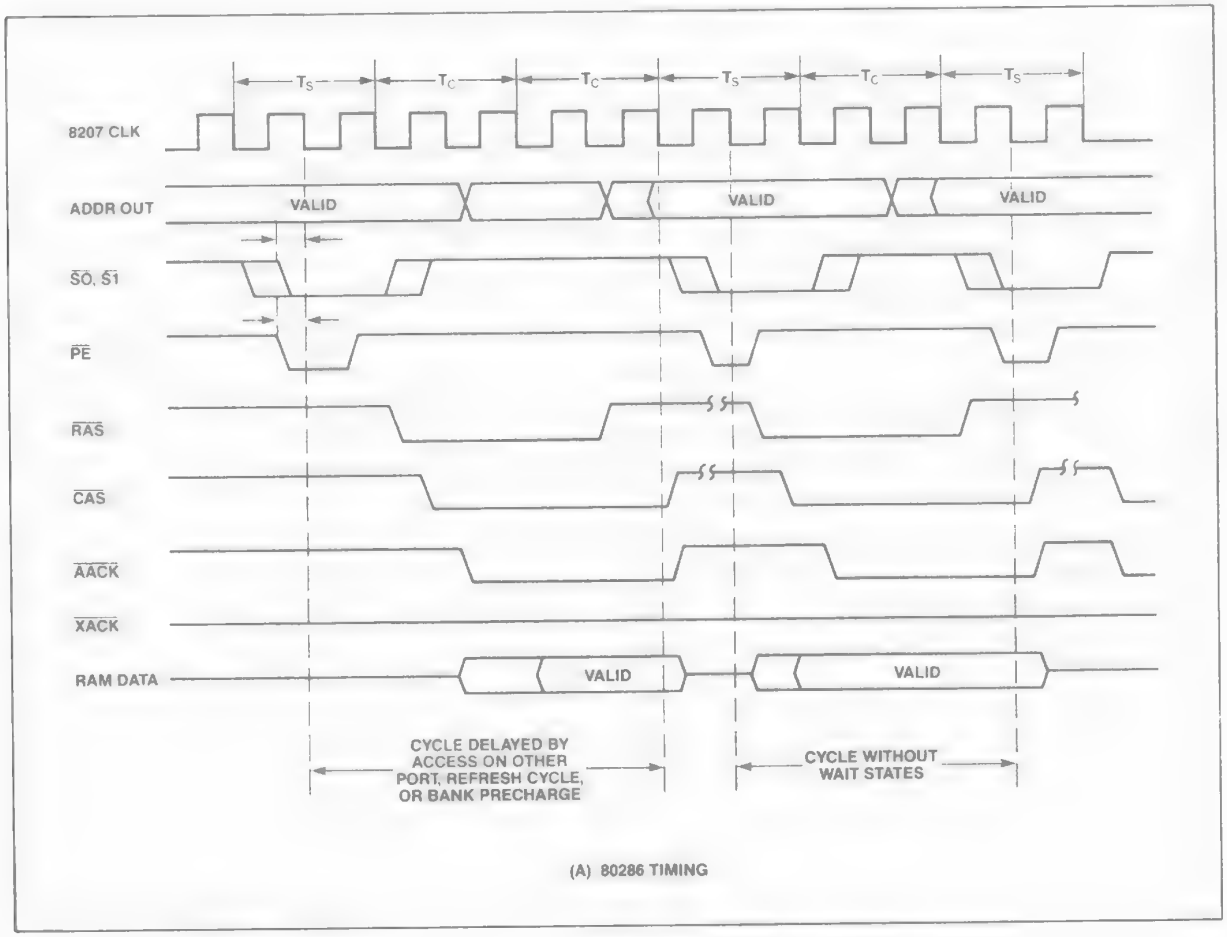

Figure 14.

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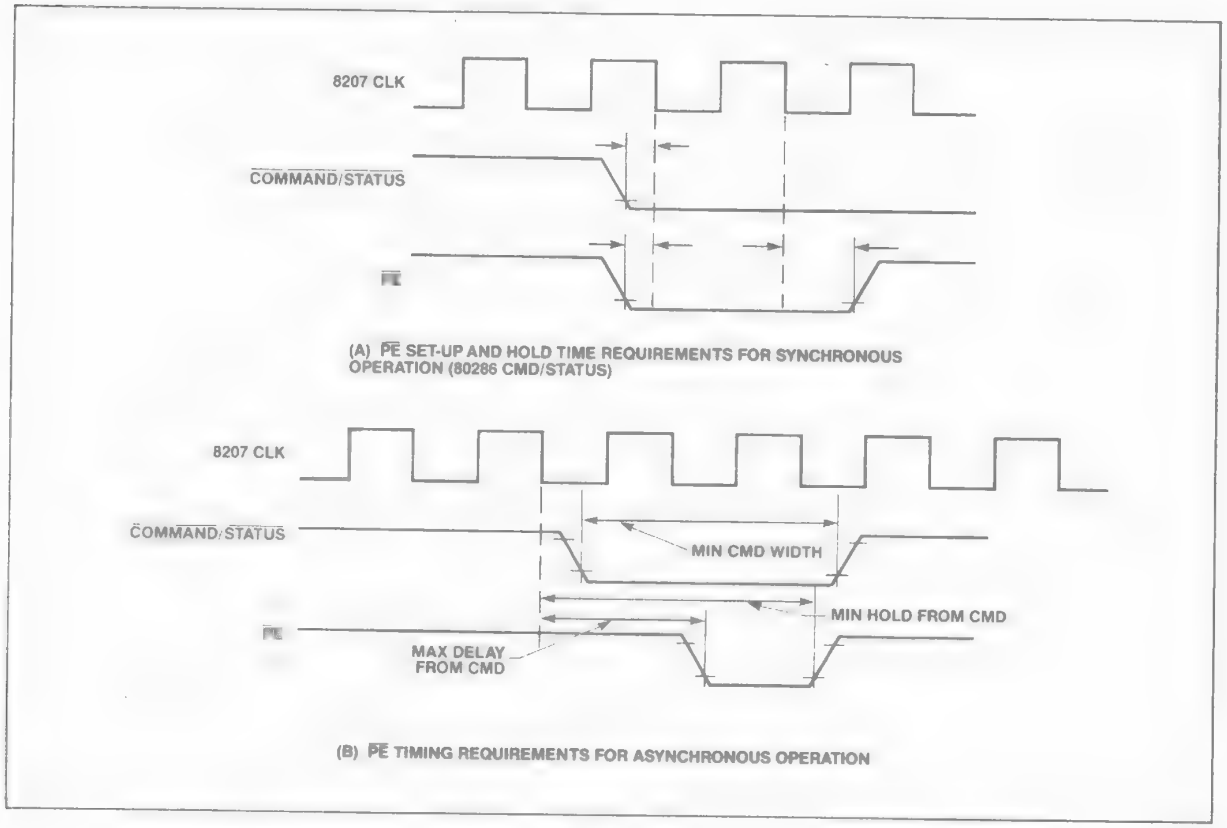

Figure 15.

Memory Acknowledge (ACK, AACK, XACK)

In system configurations without error correction, two memory acknowledge signals per port are supplied by the 8207. They are the Advanced Acknowledge strobe ($\overline{AACK}$) and the Transfer Acknowledge strobe ($\overline{XACK}$). The CFS programming bit determines for which processor $\overline{AACKA}$ and $\overline{AACKB}$ are optimized, either 80286 (CFS = 1) or 8086/186 (CFS = 0), while the SA and SB programming bits optimize $\overline{AACK}$ for synchronous operation ("early" $\overline{AACK}$) or asynchronous operation ("late" $\overline{AACK}$).

Both the early and late $\overline{AACK}$ strobes are three clocks long for CFS = 1 and two clocks long for CFS = 0. The $\overline{XACK}$ strobe is asserted when data is valid (for reads) or when data may be removed (for writes) and meets the Multibus requirements. $\overline{XACK}$ is removed asynchronously by the command going inactive. Since in a synchronous operation the 8207 removes read data before late $\overline{AACK}$ or $\overline{XACK}$ is recognized by the CPU, the user must provide for data latching in the system until the CPU reads the data. In synchronous operation, data latching is unnecessary since the 8207 will not remove data until the CPU has read it.

In ECC-based systems there is one memory acknowledge ($\overline{ACK}$) per port and a programming bit associated with each acknowledge. If the X programming bit is high, the strobe is configured as $\overline{XACK}$, while if the bit is low, the strobe is configured as $\overline{AACK}$. As in non-ECC, the SA and SB programming bits determine whether the $\overline{AACK}$ strobe is early or late.

Data will always be valid a fixed time after the occurrence of the advanced acknowledge. Table 9 summarizes the various transfer acknowledge options.

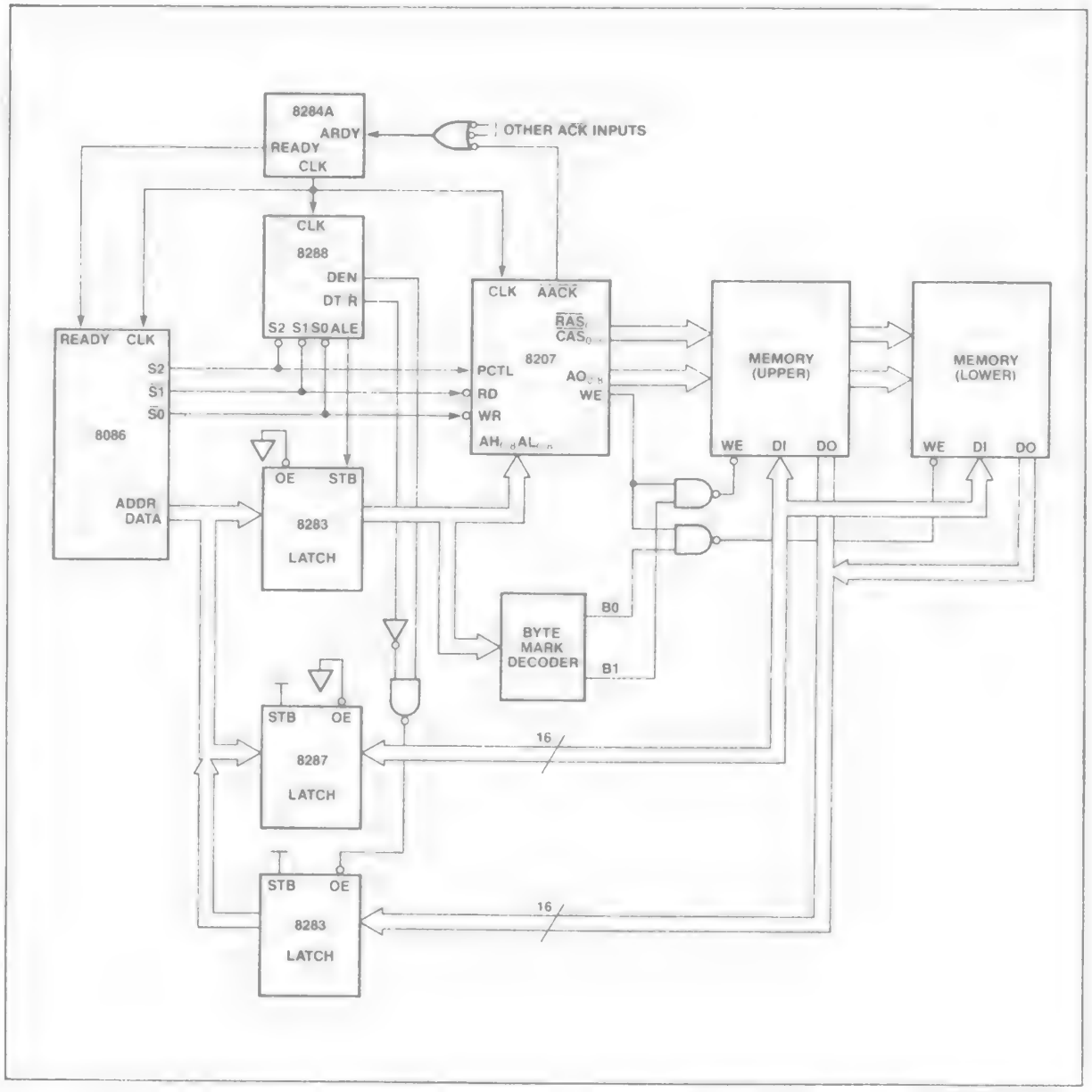

Figure 16. 8086 Hook-up to 8207 Non-ECC Synchronous System-Single Port.

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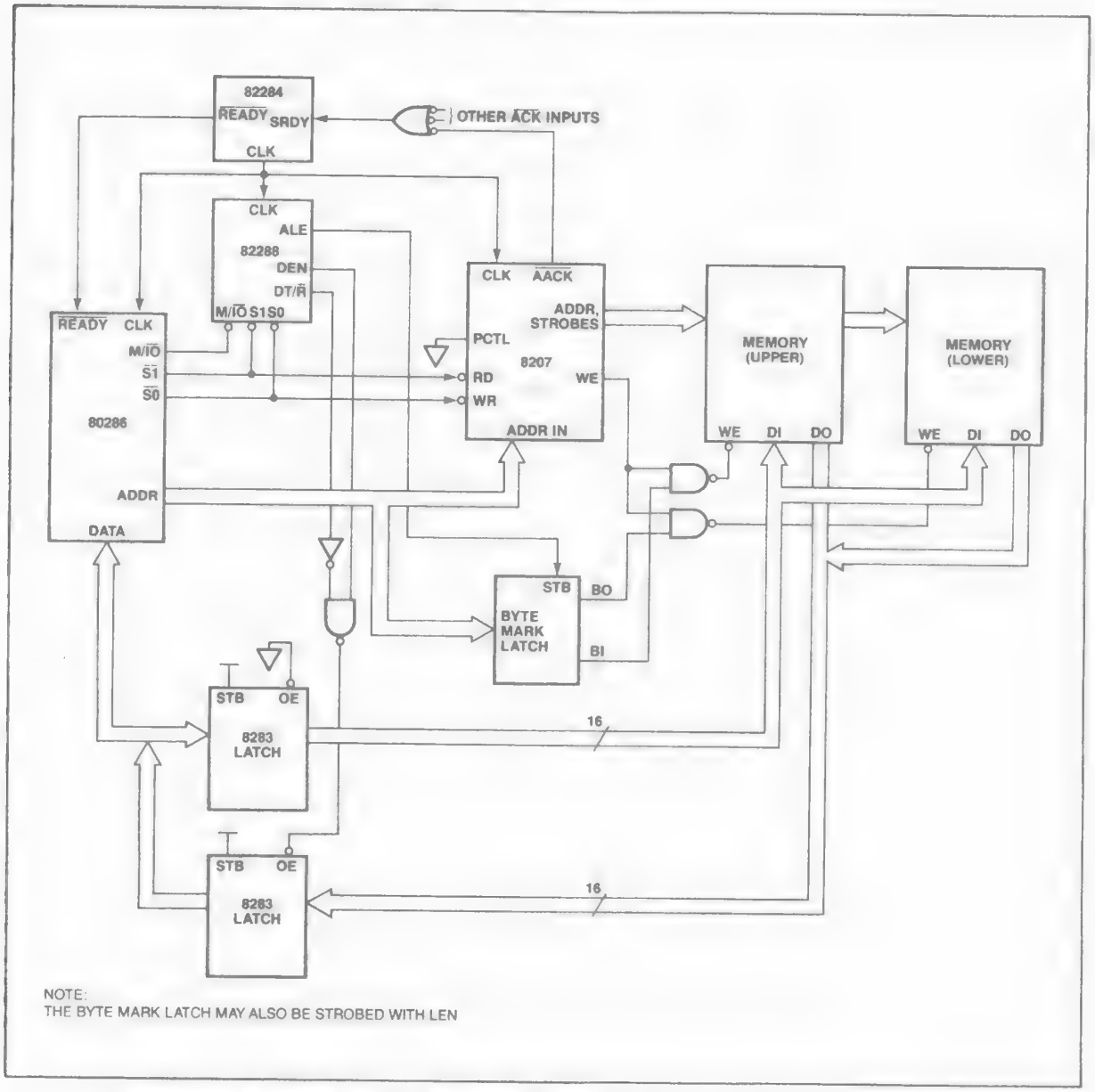


NOTE:
THE BYTE MARK LATCH MAY ALSO BE STROBED WITH LEN

Figure 17. 80286 Hook-up to 8207 Non-ECC Synchronous System–Single Port.

Table 8. Processor Interface/Acknowledge Summary

CYCLE	PROCESSOR	REQUEST TYPE	SYNC/ASYNC INTERFACE	ACKNOWLEDGE TYPE
FAST CYCLE CFS=1	80286	STATUS	SYNC	$\overline{EAACK}$
	80286	STATUS	ASYNC	$\overline{LAACK}$
	80286	COMMAND	SYNC	$\overline{EAACK}$
	80286	COMMAND	ASYNC	$\overline{LAACK}$
	8086/80186	STATUS	ASYNC	$\overline{LAACK}$
	8086/80186	COMMAND	ASYNC	$\overline{LAACK}$
	MULTIBUS	COMMAND	ASYNC	$\overline{XACK}$
SLOW CYCLE CFS=0	8086/80186	STATUS	SYNC	$\overline{EAACK}$
	8086/80186	STATUS	ASYNC	$\overline{LAACK}$
	8086/80186	COMMAND	SYNC	$\overline{EAACK}$
	8086/80186	COMMAND	ASYNC	$\overline{LAACK}$
	MULTIBUS	COMMAND	ASYNC	$\overline{XACK}$

Table 9. Memory Acknowledge Option Summary

	Synchronous	Asynchronous	XACK
Fast Cycle	AACK Optimized for Local 80286	AACK Optimized for Remote 80286	Multibus Compatible
Slow Cycle	AACK Optimized for Local 8086/186	AACK Optimized for Remote 8086/186	Multibus Compatible

Test Modes

Two special test modes exist in the 8207 to facilitate testing. Test Mode 1 (non-ECC mode) splits the refresh address counter into two separate counters and Test Mode 2 (ECC mode) presets the refresh address counter to a value slightly less than rollover.

Test Mode 1 splits the address counter into two, and increments both counters simultaneously with each refresh address update. By generating external refresh requests, the tester is able to check for proper operation of both counters. Once proper individual counter operation has been established, the 8207 must be returned to normal mode and a second test performed to check that the carry from the first counter increments the second counter. The outputs of the counters are presented-on the address out bus with the same timing as the row and column addresses of a normal scrubbing operation. During Test Mode 1, memory initialization is inhibited, since the 8207, by definition, is in non-ECC mode.

Test Mode 2 sets the internal refresh counter to a value slightly less than rollover. During functional testing other than that covered in Test Mode 1, the 8207 will normally be set in Test Mode 2. Test Mode 2 eliminates memory initialization in ECC mode. This allows quick examination of the circuitry which brings the 8207 out of memory initialization and into normal operation. Test Mode 2 is also useful for quick reset response in ECC systems.

PACKAGE

The 8207 is packaged in a 68-pin, leadless JEDEC type A hermetic chip carrier. Figure 18 illustrates the package, and Figure 19 is the pinout.

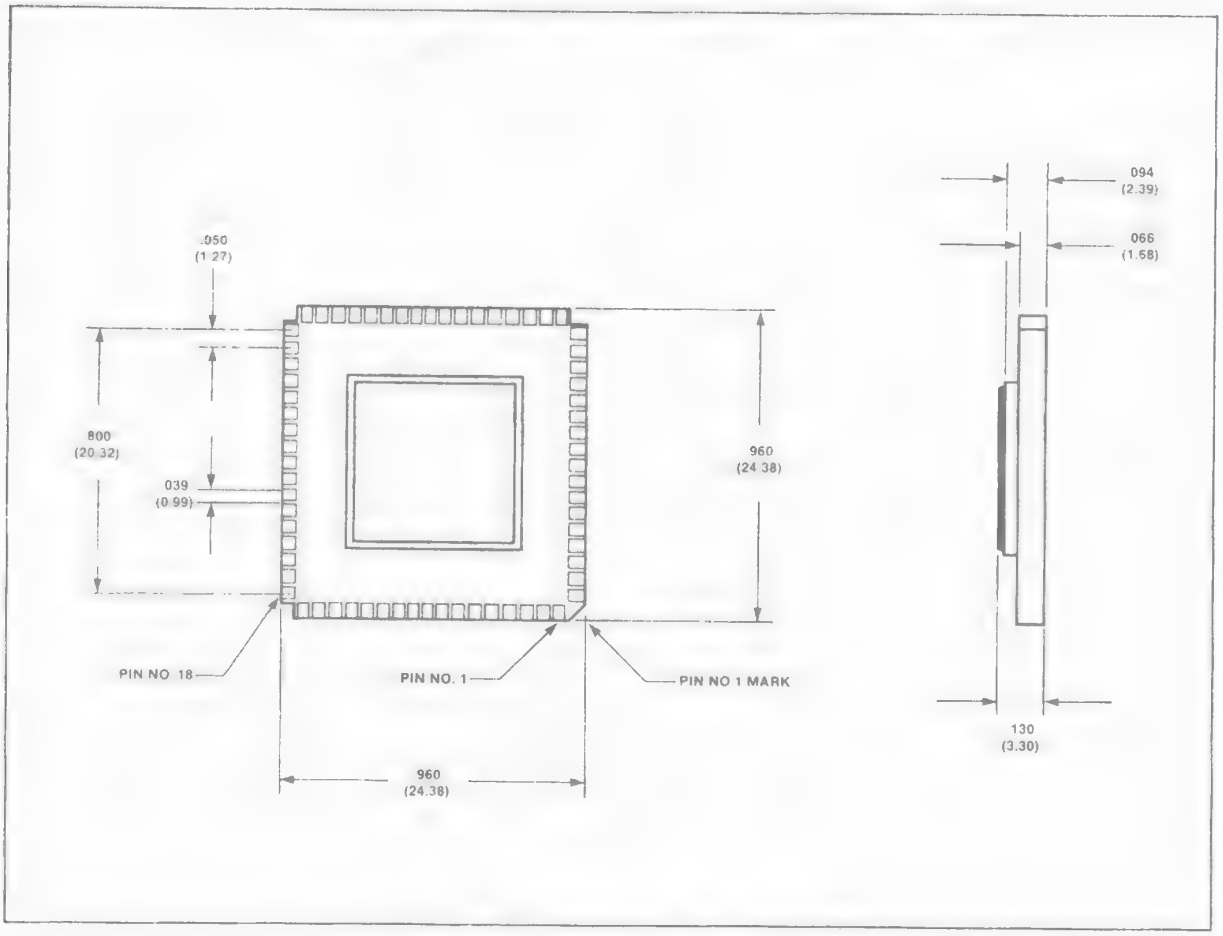


Figure 18. 8207 JEDEC Type A Package

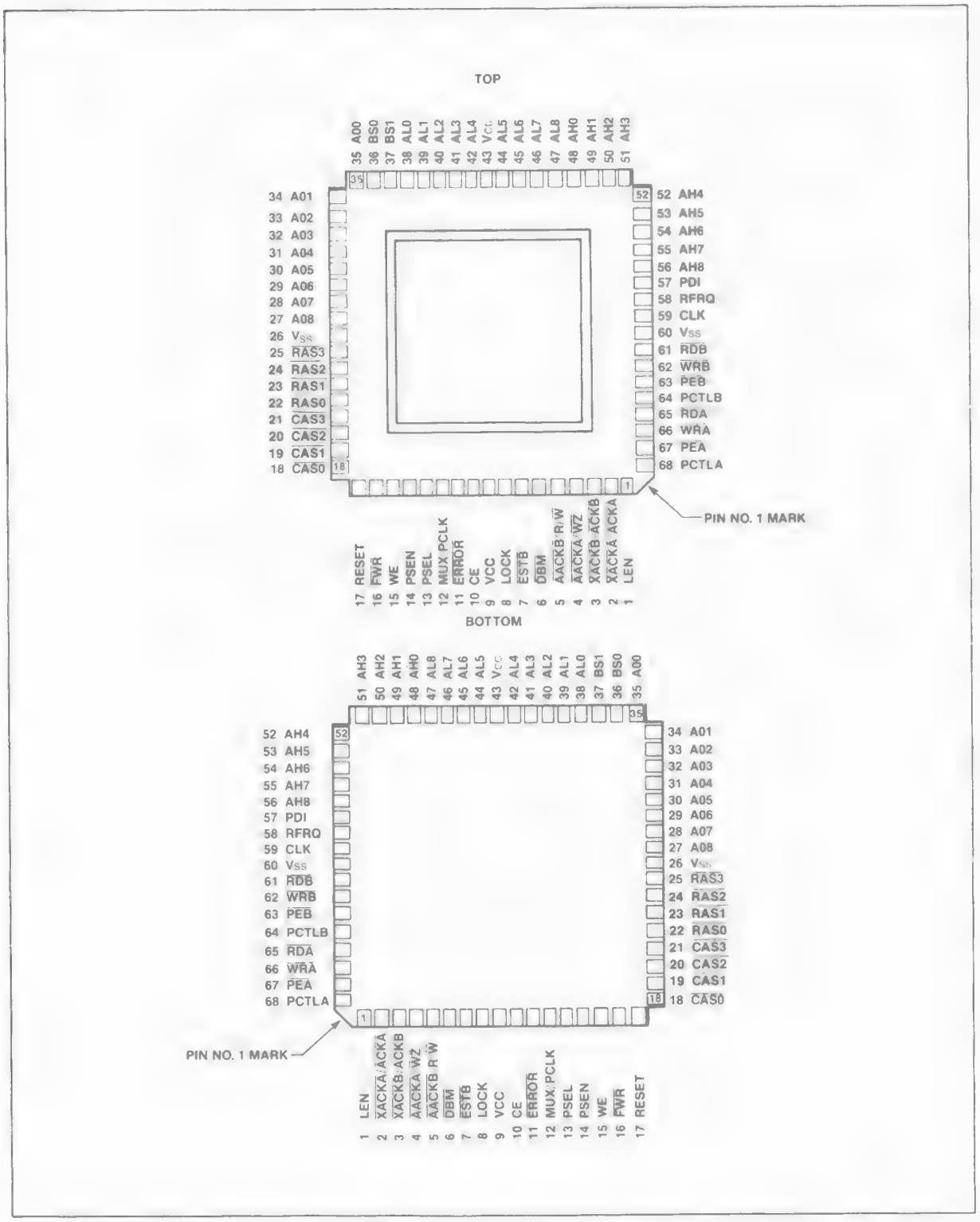


Figure 19. 8207 Pinout Diagram

NOTICE: The pinouts are not final specifications and are subject to change.

PRELIMINARY

8231A
ARITHMETIC PROCESSING UNIT

- Fixed Point Single and Double Precision (16/32 Bit)
- Floating Point Single Precision (32 Bit)
- Binary Data Formats
- Add, Subtract, Multiply and Divide
- Trigonometric and Inverse Trigonometric Functions
- Square Roots, Logarithms, Exponentiation
- Float to Fixed and Fixed to Float Conversions
- Stack Oriented Operand Storage
- Compatible with MCS-80™ and MCS-85™ Microprocessor Families
- Direct Memory Access or Programmed I/O Data Transfers
- End of Execution Signal
- General Purpose 8-Bit Data Bus Interface
- Standard 24 Pin Package
- +12 Volt and +5 Volt Power Supplies
- Advanced N-Channel Silicon Gate HMOS Technology

The Intel® 8231A Arithmetic Processing Unit (APU) is a monolithic HMOS LSI device that provides high performance fixed and floating point arithmetic and floating point trigonometric operations. It may be used to enhance the mathematical capability of a wide variety of processor-oriented systems. Chebyshev polynomials are used in the implementation of the APU algorithms.

All transfers, including operand, result, status and command information, take place over an 8-bit bidirectional data bus. Operands are pushed onto an internal stack and commands are issued to perform operations on the data in the stack. Results are then available to be retrieved from the stack.

Transfers to and from the APU may be handled by the associated processor using conventional programmed I/O, or may be handled by a direct memory access controller for improved performance. Upon completion of each command, the APU issues an end of execution signal that may be used as an interrupt by the CPU to help coordinate program execution.

In January 1981 Intel will be converting from 8231 to 8231A. The 8231A provides enhancements over the 8231 to allow use in both asynchronous and synchronous systems.

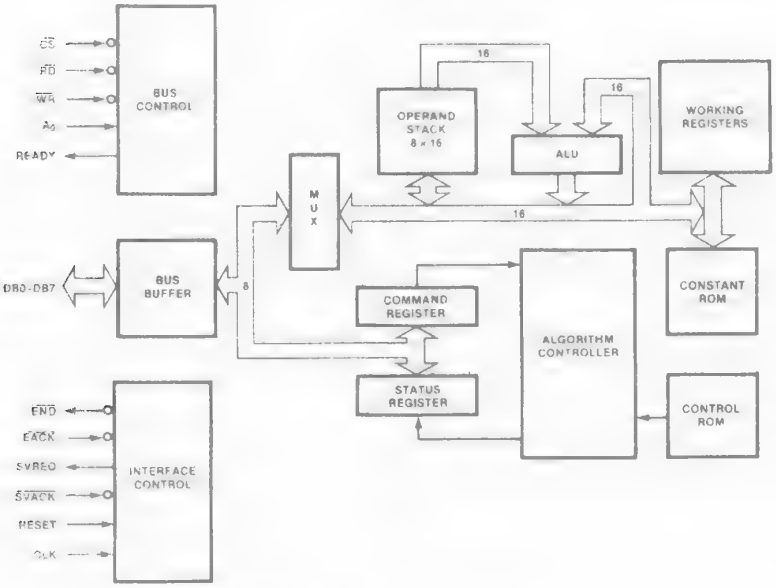


Figure 1. Block Diagram

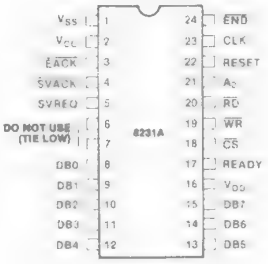


Figure 2. Pin Configuration

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
V_{CC}	2		**Power:** +5 Volt power supply.
V_{DD}	16		**Power:** +12 Volt power supply.
V_{SS}	1		**Ground.**
CLK	23	I	**Clock:** An external, TTL compatible, timing source is applied to the CLK pin.
RESET	22	I	**Reset:** The active high reset signal provides initialization for the chip. RESET also terminates any operation in progress. RESET clears the status register and places the 8231A into the idle state. Stack contents and command registers are not affected (5 clock cycles).
$\overline{CS}$	18	I	**Chip Select:** $\overline{CS}$ is an active low input signal which selects the 8231A and enables communication with the data bus.
A_0	21	I	**Address:** In conjunction with the $\overline{RD}$ and WR signals, the A_0 control line establishes the type of communication that is to be performed with the 8231A as shown below:

A_0	$\overline{RD}$	$\overline{WR}$	Function
0	1	0	Enter data byte into stack
0	0	1	Read data byte from stack
1	1	0	Enter command
1	0	1	Read status

Symbol	Pin No.	Type	Name and Function
$\overline{RD}$	20	I	**Read:** This active low input indicates that data or status is to be read from the 8231A if CS is low.
$\overline{WR}$	19	I	**Write:** This active low input indicates that data or a command is to be written into the 8231A if CS is low.
$\overline{EACK}$	3	I	**End of Execution:** This active low input clears the end of execution output signal ($\overline{END}$). If $\overline{EACK}$ is tied low, the $\overline{END}$ output will be a pulse that is one clock period wide.
$\overline{SVACK}$	4	I	**Service Request:** This active low input clears the service request output (SVREQ).
$\overline{END}$	24	O	**End:** This active low, open-drain output indicates that execution of the previously entered command is complete. It can be used as an interrupt request and is cleared by $\overline{EACK}$, RESET or any read or write access to the 8231.
SVREQ	5	O	**Service Request:** This active high output signal indicates that command execution is complete and that post execution service was requested in the previous command byte. It is cleared by $\overline{SVACK}$, the next command output to the device, or by RESET.
READY	17	O	**Ready:** This active high output indicates that the 8231A is able to accept communication with the data bus. When an attempt is made to read data, write data or to enter a new command while the 8231A is executing a command, READY goes low until execution of the current command is complete (See READY Operation, p. 5).
DB0-DB7	8-15	I/O	**Data Bus:** These eight bidirectional lines provide for transfer of commands, status and data between the 8231A and the CPU. The 8231A can drive the data bus only when CS and RD are low.

COMMAND STRUCTURE

Each command entered into the 8231A consists of a single 8-bit byte having the format illustrated below:

Bits 0-4 select the operation to be performed as shown in the table. Bits 5-6 select the data format appropriate to the selected operation. If bit 5 is a 1, a fixed point data format is specified. If bit 5 is a 0, floating point format is specified. Bit 6 selects the precision of the data to be operated upon by fixed point commands only (if bit 5 = 0, bit 6 must be 0). If bit 6 is a 1, single-precision (16-bit) operands are assumed. If bit 6 is a 0, double-precision (32-bit) operands are indicated. Results are undefined for all illegal combinations of bits in the command byte. Bit 7 indicates whether a service request is to be issued after the command is executed. If bit 7 is a 1, the service request output (SVREQ) will go high at the conclusion of the command and will remain high until reset by a low level on the service acknowledge pin ($\overline{SVACK}$) or until completion of execution of the succeeding command where service request (bit 7) is 0. Each command issued to the 8231A requests post execution service based upon the state of bit 7 in the command byte. When bit 7 is a 0, SVREQ remains low.

Table 2. 32-Bit Floating Point Instructions

Instruction	Description	Hex[1] Code	Stack Contents[2] After Execution A	B	C	D	Status Flags[4] Affected
ACOS	Inverse Cosine of A	0 [illegible]	R	U	U	U	S, Z, E
ASIN	Inverse Sine of A	0 5	R	U	U	U	S, Z, E
ATAN	Inverse Tangent of A	0 7	R	B	U	U	S, Z
CHSF	Sign Change of A	1 5	R	B	C	[illegible]	S, Z
COS	Cosine of A (radians)	0 3	R	B	U	U	S, Z
EXP	e^A Function	0 A	[illegible]	B	U	U	S, Z, E
FADD	Add A and B	1 0	R	C	D	U	S, Z, E
FDIV	Divide B by A	1 3	R	C	D	U	S, Z, E
FLTD	32-Bit Integer to Floating Point Conversion	1 C	[illegible]	[illegible]	C	U	S, Z
FLTS	16-Bit Integer to Floating Point Conversion	1 D	R	B	C	U	S, Z
FMUL	Multiply A and B	1 2	[illegible]	C	[illegible]	U	S, Z, E
FSUB	Subtract A from B	1 1	R	C	D	U	S, Z, E
LOG	Common Logarithm (base 10) of A	0 8	R	B	U	U	S, Z, E
LN	Natural Logarithm of A	0 [illegible]	[illegible]	B	U	U	S, Z, E
POPF	Stack Pop	1 8	[illegible]	C	D	A	S, Z
PTOF	Stack Push	1 7	A	A	[illegible]	C	S, Z
PUPI	Push π onto Stack	1 A	R	A	B	C	S, Z
PWR	B^A Power Function	0 [illegible]	[illegible]	C	U	U	S, Z, E
SIN	Sine of A (radians)	0 2	[illegible]	B	U	U	S, Z
SQRT	Square Root of A	0 1	[illegible]	B	C	U	S, Z, E
TAN	Tangent of A (radians)	0 4	R	[illegible]	U	U	S, Z, E
XCHF	Exchange A and B	1 9	B	A	C	D	S, Z

Table 3. 32-Bit Integer Instructions

Instruction	Description	Hex[1] Code	Stack Contents[2] After Execution A	B	C	D	Status Flags[4] Affected
CHSD	Sign Change of A	3 4	[illegible]	[illegible]	C	D	S, Z, O
DADD	Add A and B	2 C	R	C	D	A	S, Z, C, E
DDIV	Divide B by A	2 F	R	C	[illegible]	U	S, Z, E
DMUL	Multiply A and B (R = lower 32-bits)	[illegible] E	[illegible]	C	D	U	S, Z, O
DMUU	Multiply A and B (R = upper 32-bits)	3 6	[illegible]	C	D	U	S, Z, O
DSUB	Subtract A from B	2 D	R	C	D	A	S, Z, C, O
FIXD	Floating Point to Integer Conversion	1 E	[illegible]	[illegible]	C	U	S, Z, O
POPD	Stack Pop	3 8	[illegible]	C	D	A	S, Z
PTOD	Stack Push	3 7	A	A	[illegible]	C	S, Z
XCHD	Exchange A and B	3 [illegible]	[illegible]	A	C	D	S, Z

Table 4. 16-Bit Integer Instructions

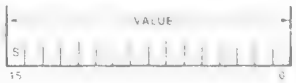
Instruction	Description	Hex[1] Code	Stack Contents[3] After Execution A_U	A_L	B_U	B_L	C_U	C_L	D_U	D_L	Status Flags[4] Affected
CHSS	Change Sign of A_U	7 4	R	A_L	B_U	B_L	C_U	C_L	D_U	D_L	S, Z, O
FIXS	Floating Point to Integer Conversion	1 F	R	B_U	B_L	C_U	C_L	U	U	U	S, Z, O
POPS	Stack Pop	7 8	A_L	B_U	B_L	C_U	C_L	D_U	D_L	A_U	S, Z
PTOS	Stack Push	7 7	A_U	A_U	A_L	B_U	B_L	C_U	C_L	D_U	S, Z
SADD	Add A_U and A_L	6 C	R	B_U	B_L	C_U	C_L	D_U	D_L	A_U	S, Z, C, E
SDIV	Divide A_L by A_U	6 F	R	B_U	B_L	C_U	C_L	D_U	D_L	U	S, Z, E
SMUL	Multiply A_L by A_U (R = lower 16-bits)	6 E	R	B_U	B_L	C_U	C_L	D_U	D_L	U	S, Z, E
SMUU	Multiply A_L by A_U (R = upper 16-bits)	7 6	R	B_U	B_L	C_U	C_L	D_U	D_L	U	S, Z, E
SSUB	Subtract A_U from A_L	6 D	R	B_U	B_L	C_U	C_L	D_U	D_L	A_U	S, Z, C, E
XCHS	Exchange A_U and A_L	7 9	A_L	A_U	B_U	B_L	C_U	C_L	D_U	D_L	S, Z
NOP	No Operation	0 0	A_U	A_L	B_U	B_L	C_U	C_L	D_U	D_L	

Notes: 1. In the hex code column, SVREQ is a 0.
2. The stack initially is composed of four 32-bit numbers (A, B, C, D). A is equivalent to Top Of Stack (TOS) and B is Next On Stack (NOS). Upon completion of a command the stack is composed of: the result (R); undefined (U); or the initial contents (A, B, C, or D).
3. The stack initially is composed of eight 16-bit numbers (A_U, A_L, B_U, B_L, C_U, C_L, D_U, D_L). A_U is the TOS and A_L is NOS. Upon completion of a command the stack is composed of: the result (R); undefined (U); or the initial contents (A_U, A_L, B_U, B_L, . . .).
4. Nomenclature: Sign (S); Zero (Z); Overflow (O); Carry (C); Error Code Field (E).

DATA FORMATS

The 8231A arithmetic processing unit handles operands in both fixed point and floating point formats. Fixed point operands may be represented in either single (16-bit operands) or double precision (32-bit operands), and are always represented as binary, two's complement values.

SINGLE PRECISION FIXED POINT FORMAT



DOUBLE PRECISION FIXED POINT FORMAT

The sign (positive or negative) of the operand is located in the most significant bit (MSB). Positive values are represented by a sign bit of zero (S = 0). Negative values are represented by the two's complement of the corresponding positive value with a sign bit equal to 1 (S = 1). The range of values that may be accommodated by each of these formats is −32,768 to +32,767 for single precision and −2,147,483,648 to +2,147,483,647 for double precision.

Floating point binary values are represented in a format that permits arithmetic to be performed in a fashion analogous to operations with decimal values expressed in scientific notation.

$$(5.83 \times 10^2)\,(8.16 \times 10^1) = (4.75728 \times 10^4)$$

In the decimal system, data may be expressed as values between 0 and 10 times 10 raised to a power that effectively shifts the implied decimal point right or left the number of places necessary to express the result in conventional form (e.g., 47,572.8). The value-portion of the data is called the mantissa. The exponent may be either negative or positive.

The concept of floating point notation has both a gain and a loss associated with it. The gain is the ability to represent the significant digits of data with values spanning a large dynamic range limited only by the capacity of the exponent field. For example, in decimal notation if the exponent field is two digits wide, and the mantissa is five digits, a range of values (positive or negative) from 1.0000×10^{-99} to $9.9999 \times 10^{+99}$ can be accommodated. The loss is that only the significant digits of the value can be represented. Thus there is no distinction in this representation between the values 123451 and 123452, for example, since each would be expressed as: 1.2345×10^5. The sixth digit has been discarded. In most applications where the dynamic range of values to be represented is large, the loss of significance, and hence accuracy of results, is a minor consideration. For greater precision a fixed point format could be chosen, although with a loss of potential dynamic range.

The 8231A is a binary arithmetic processor and requires that floating point data be represented by a fractional mantissa value between .5 and 1 multiplied by 2 raised to an appropriate power. This is expressed as follows:

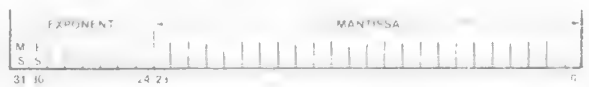
$$\text{value} = \text{mantissa} \times 2^{\text{exponent}}$$

For example, the value 100.5 expressed in this form is $0.1100\ 1001 \times 2^7$. The decimal equivalent of this value may be computed by summing the components (powers of two) of the mantissa and then multiplying by the exponent as shown below:

$$\begin{aligned}\text{value} &= (2^{-1} + 2^{-2} + 2^{-5} + 2^{-8}) \times 2^7 \\ &= 0.5 + 0.25 + 0.03125 + 0.00290625) \times 128 \\ &= 0.78515625 \times 128 \\ &= 100.5\end{aligned}$$

FLOATING POINT FORMAT

The format for floating point values in the 8231A is given below. The mantissa is expressed as a 24-bit (fractional) value; the exponent is expressed as a two's complement 7-bit value having a range of −64 to +63. The most significant bit is the sign of the mantissa (0 = positive, 1 = negative), for a total of 32 bits. The binary point is assumed to be to the left of the most significant mantissa bit (bit 23). All floating point data values must be normalized. Bit 23 must be equal to 1, except for the value zero, which is represented by all zeros.

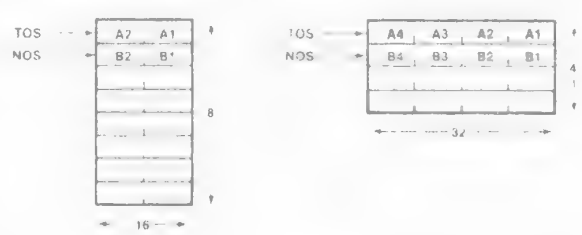


The range of values that can be represented in this format is $\pm(2.7 \times 10^{-20}$ to $9.2 \times 10^{18})$ and zero.

FUNCTIONAL DESCRIPTION

STACK CONTROL

The user interface to the 8231A includes access to an 8 level 16-bit wide data stack. Since single precision fixed point operands are 16-bits in length, eight such values may be maintained in the stack. When using double precision fixed point or floating point formats four values may be stored. The stack in these two configurations can be visualized as shown below:



Data are written onto the stack, eight bits at a time, in the order shown (A1, A2, A3, . . .). Data are removed from the stack in reverse byte order (A4, A3, A2 . . .). Data should be entered onto the stack in multiples of the number of bytes appropriate to the chosen data format.

DATA ENTRY

Data entry is accomplished by bringing the chip select ($\overline{CS}$), the command/data line (A_0), and $\overline{WR}$ low, as shown in the timing diagram. The entry of each new data word "pushes down" the previously entered data and places the new byte on the top of stack (TOS). Data on the bottom of the stack prior to a stack entry are lost.

DATA REMOVAL

Data are removed from the stack in the 8231A by bringing chip select ($\overline{CS}$), command/data (A_0), and $\overline{RD}$ low as shown in the timing diagram. The removal of each data word redefines TOS so that the next successive byte to be removed becomes TOS. Data removed from the stack rotates to the bottom of the stack.

COMMAND ENTRY

After the appropriate number of bytes of data have been entered onto the stack, a command may be issued to perform an operation on that data. Commands which require two operands for execution (e.g., add) operate on the TOS and NOS values. Single operand commands operate only on the TOS.

Commands are issued to the 8231A by bringing the chip select ($\overline{CS}$) line low, command data (A_0) line high, and $\overline{WR}$ line low as indicated by the timing diagram. After a command is issued, the CPU can continue execution of its program concurrently with the 8231A command execution.

COMMAND COMPLETION

The 8231A signals the completion of each command execution by lowering the End Execution line ($\overline{END}$). Simultaneously, the busy bit in the status register is cleared and the Service Request bit of the command register is checked. If it is a "1" the service request output level (SVREQ) is raised. $\overline{END}$ is cleared on receipt of an active low End Acknowledge ($\overline{EACK}$) pulse. Similarly, the service request line is cleared by recognition of an active low Service Acknowledge ($\overline{SVACK}$) pulse.

READY OPERATION

An active high ready (READY) is provided. This line is high in its quiescent state and is pulled low by the 8231A under the following conditions:

1. A previously initiated operation is in progress (device busy) and Command Entry has been attempted. In this case, the READY line will be pulled low and remain low until completion of the current command execution. It will then go high, permitting entry of the new command.
2. A previously initiated operation is in progress and stack access has been attempted. In this case, the READY line will be pulled low, will remain in that state until execution is complete, and will then be raised to permit completion of the stack access.
3. The 8231A is not busy, and data removal has been requested. READY will be pulled low for the length of time necessary to transfer the byte from the top of stack to the interface latch, and will then go high, indicating availability of the data.
4. The 8231A is not busy, and a data entry has been requested. READY will be pulled low for the length of time required to ascertain if the preceding data byte, if any, has been written to the stack. If so READY will immediately go high. If not, READY will remain low until the interface latch is free and will then go high.
5. When a status read has been requested, READY will be pulled low for the length of time necessary to transfer the status to the interface latch, and will then be raised to permit completion of the status read. Status may be read whether or not the 8231A is busy.

When READY goes low, the APU expects the bus control signals present at the time to remain stable until READY goes high.

DEVICE STATUS

Device status is provided by means of an internal status register whose format is shown below:

BUSY: Indicates that 8231A is currently executing a command (1 = Busy)

SIGN: Indicates that the value on the top of stack is negative (1 = Negative)

ZERO: Indicates that the value on the top of stack is zero (1 = Value is zero)

ERROR CODE: This field contains an indication of the validity of the result of the last operation. The error codes are:

- 0000 — No error
- 1000 — Divide by zero
- 0100 — Square root or log of negative number
- 1100 — Argument of inverse sine, cosine, or e^x too large
- XX10 — Underflow
- XX01 — Overflow

CARRY: Previous operation resulted in carry or borrow from most significant bit. (1 = Carry/Borrow, 0 = No Carry/No Borrow.)

If the BUSY bit in the status register is a one, the other status bits are not defined; if zero, indicating not busy, the operation is complete and the other status bits are defined as given above.

READ STATUS

The 8231A status register can be read by the CPU at any time (whether an operation is in progress or not) by bringing the chip select ($\overline{CS}$) low, the command/data line (A_0) high, and lowering $\overline{RD}$. The status register is then gated onto the data bus and may be input by the CPU.

EXECUTION TIMES

Timing for execution of the 8231A command set is contained below. All times are given in terms of clock cycles. Where substantial variation of execution times

is possible, the minimum and maximum values are quoted; otherwise, typical values are given. Variations are data dependent.

Total execution times may require allowances for operand transfer into the APU, command execution, and result retrieval from the APU. Except for command execution, these times will be heavily influenced by the nature of the data, the control interface used, the speed of memory, the CPU used, the priority allotted to DMA and Interrupt operations, the size and number of operands to be transferred, and the use of chained calculations, etc.

Table 5. Command Execution Times

Command Mnemonic	Clock Cycles	Command Mnemonic	Clock Cycles	Command Mnemonic	Clock Cycles	Command Mnemonic	Clock Cycles
SADD	17	FADD	54-368	LN	4298-6956	POPF	12
SSUB	30	FSUB	70-370	EXP	3794-4878	XCHS	18
SMUL	84-94	FMUL	146-168	PWR	8290-12032	XCHD	26
SMUU	80-98						
SDIV	84-94	FDIV	154-184	NOP	4	XCHF	26
DADD	21	SORT	800	CHSS	23	PUPI	16
DSUB	38	SIN	4464	CHSD	27		
DMUL	194-210	COS	4118	CHSF	18		
DMUU	182-218						
DDIV	208	TAN	5754	PTOS	16		
FIXS	92-216	ASIN	7668	PTOD	20		
FIXD	100-346	ACOS	7734	PTOF	20		
FLTS	98-186	ATAN	8000	POPS	10		
FLTD	98-378	LOG	4474-7132	POPD	12		

DERIVED FUNCTION DISCUSSION

Computer approximations of transcendental functions are often based on some form of polynomial equation, such as:

$$F(X) = A_0 + A_1X + A_2X^2 + A_3X^3 + A_4X^4 \ldots \quad (1\text{-}1)$$

The primary shortcoming of an approximation in this form is that it typically exhibits very large errors when the magnitude of $|X|$ is large, although the errors are small when $|X|$ is small. With polynomials in this form, the error distribution is markedly uneven over any arbitrary interval.

A set of approximating functions exists that not only minimizes the maximum error but also provides an even distribution of errors within the selected data representation interval. These are known as Chebyshev Polynomials and are are based upon cosine functions. These functions are defined as follows:

$$T_n(X) = \text{Cos } n\theta; \text{ where } n = 0,1,2 \ldots \quad (1\text{-}2)$$
$$\theta = \text{Cos}^{-1}X$$

The various terms of the Chebyshev series can be computed as shown below:

$$T_0(X) = \text{Cos}(0 \cdot \theta) = \text{Cos}(0) = 1 \quad (1\text{-}4)$$
$$T_1(X) = \text{Cos}(\text{Cos}^{-1}X) = X \quad (1\text{-}5)$$
$$T_2(X) = \text{Cos } 2\theta = 2\text{Cos}^2\theta - 1 = 2\text{Cos}^2(\text{Cos}^{-1}X) - 1 = 2X^2 - 1 \quad (1\text{-}6)$$

In general, the next term in the Chebyshev series can be recursively derived from the previous term as follows:

$$T_n(X) = 2X[T_n - 1(X)] - T_n - 2(X); n \geqslant 2 \quad (1\text{-}7)$$

Common logarithms are computed by multiplication of the natural logarithm by the conversion factor 0.43429448 and the error function is therefore the same as that for natural logarithm. The power function is realized by combination of natural log and exponential functions according to the equation:

$$X^Y = e^{y\text{Ln}x}.$$

The error for the power function is a combination of that for the logarithm and exponential functions.

Each of the derived functions is an approximation of the true function. Thus the result of a derived function will have an error. The absolute error is the difference between the function's result and the true result. A more useful measure of the function's error is relative error (absolute error/true result). This gives a measurement of the significant digits of algorithm accuracy. For the derived functions except LN, LOG, and PWR the relative error is typically 4×10^{-7}. For PWR the relative error is the summation of the EXP and LN errors, 7×10^{-7}. For LN and LOG, the absolute error is 2×10^{-7}.

APPLICATION INFORMATION

The diagram in Figure 4 shows the interface connections for the APU with operand transfers handled by an 8237 DMA controller, and CPU coordination handled by an Interrupt Controller. The APU interrupts the CPU to indicate that a command has been completed. When the performance enhancements provided by the DMA and Interrupt operations are not required, the APU interface can be simplified as shown in Figure 3. The 8231A APU is designed with a general purpose 8-bit data bus and interface control so that it can be conveniently used with any general 8-bit processor.

In many systems it will be convenient to use the microcomputer system clock to drive the APU clock input. In the case of 8080A systems it would be the ϕ2TTL signal. Its cycle time will usually fall in the range of 250 ns to 1000 ns, depending on the system speed.

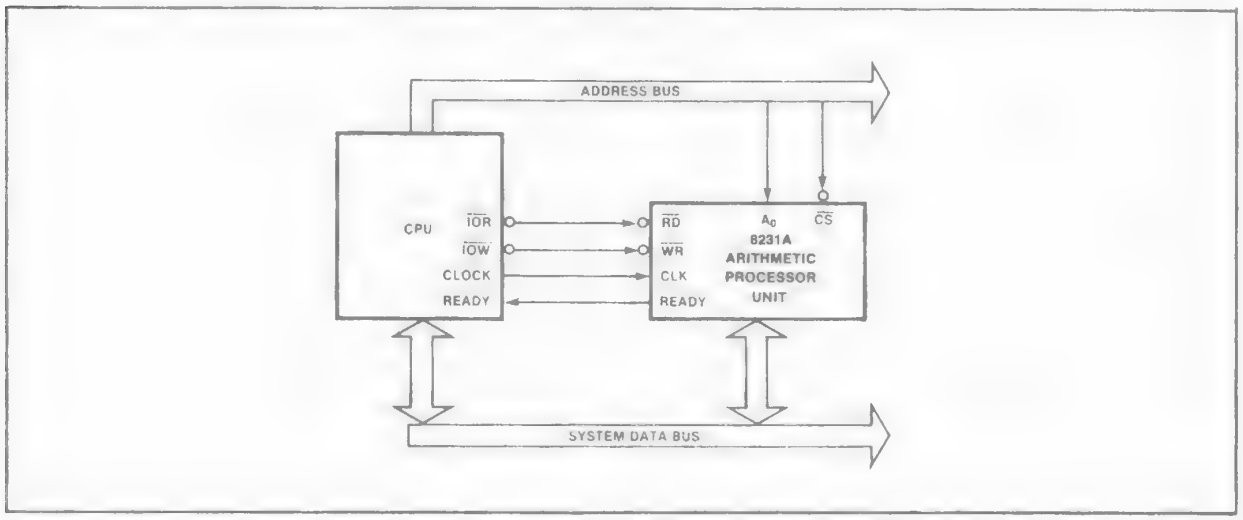


Figure 3. Minimum Configuration Example

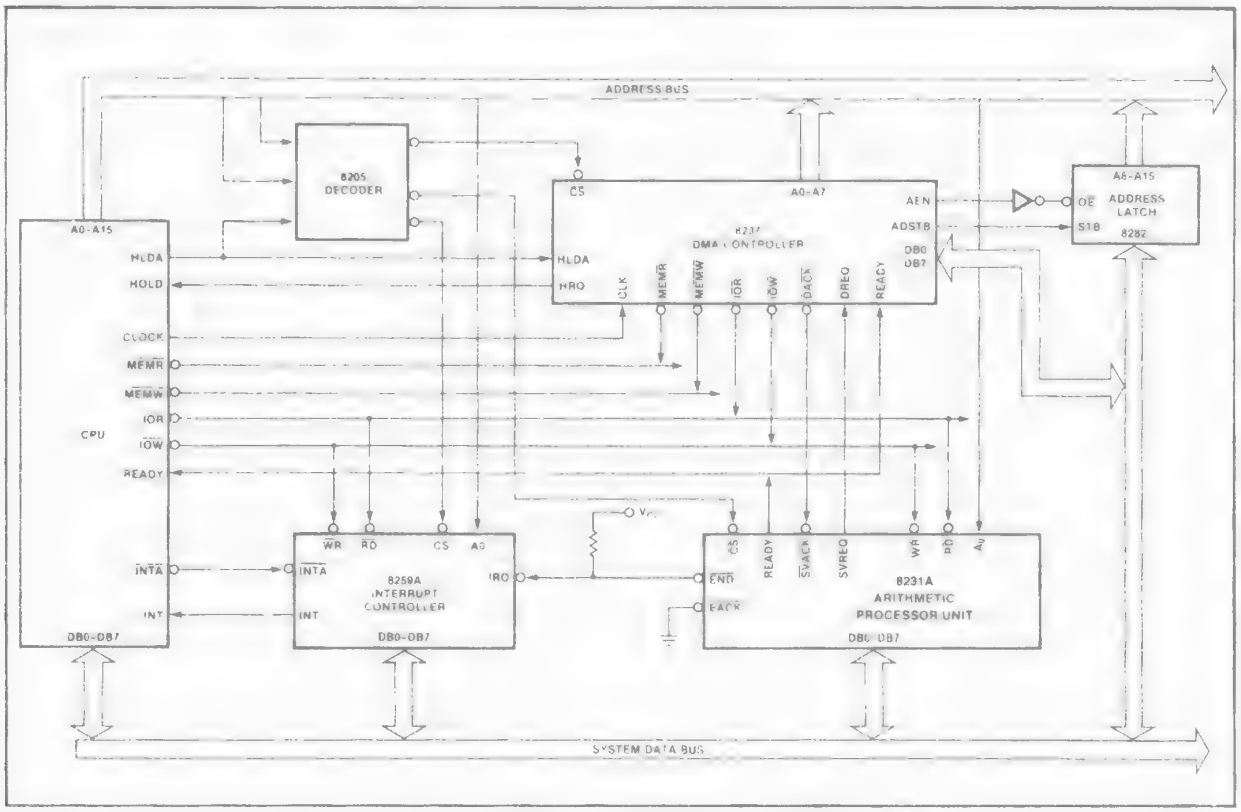


Figure 4. High Performance Configuration Example

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ABSOLUTE MAXIMUM RATINGS*

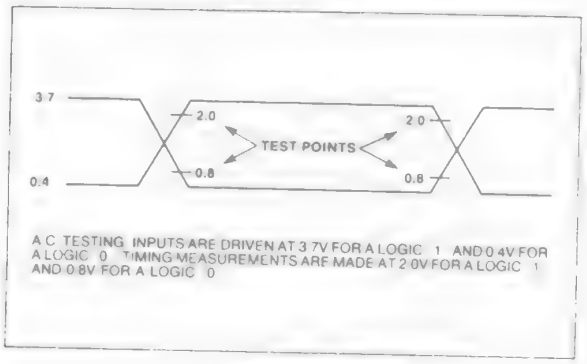
Storage Temperature . . . . . – 65°C to + 150°C
Ambient Temperature Under Bias . . . . . 0°C to 70°C
V_{DD} with Respect to V_{SS} . . . . . – 0.5V to + 15.0V
V_{CC} with Respect to V_{SS} . . . . . – 0.5V to + 7.0V
All Signal Voltages with Respect to V_{SS} . . . . . – 0.5V to + 7.0V
Power Dissipation 2.0W

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may effect device reliability.*

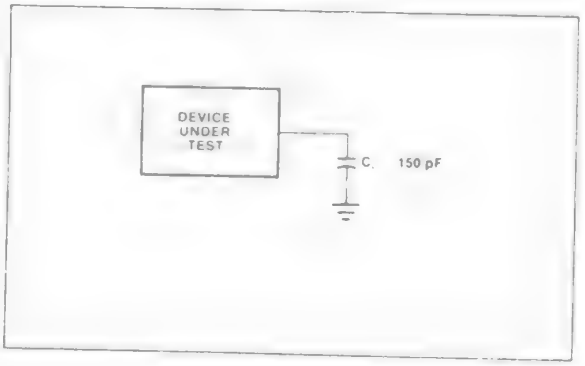
D.C. AND OPERATING CHARACTERISTICS (T_A = 0°C to 70°C, V_{SS} = 0V, V_{CC} = +5V ± 10%, V_{DD} = +12V ± 10%)

Parameters	Description	Min.	Typ.	Max.	Units	Test Conditions
V_{OH}	Output HIGH Voltage	3.7			Volts	I_{OH} = – 200 μA
V_{OL}	Output LOW Voltage			0.4	Volts	I_{OL} = 3.2 mA
V_{IH}	Input HIGH Voltage	2.0		V_{CC}	Volts	
V_{IL}	Input LOW Voltage	– 0.5		0.8	Volts	
I_{IL}	Input Load Current			± 10	μA	$V_{SS} \le V_{IN} \le V_{CC}$
I_{OFL}	Data Bus Leakage			± 10	μA	V_{SS} +0.45 ≤ V_{OUT} ≤ V_{CC}
I_{CC}	V_{CC} Supply Current		50	95	mA	
I_{DD}	V_{DD} Supply Current		50	95	mA	
C_O	Output Capacitance		[illegible]		pF	fc = 1.0 MHz, Inputs = 0V
C_I	Input Capacitance		5		pF	
C_{IO}	I/O Capacitance		10		pF	

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING LOAD CIRCUIT



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A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{SS} = 0V, V_{CC} = +5V ± 10%, V_{DD} = +12V ± 10%)

READ OPERATION

Symbol	Parameter		8231A-8		8231A-3		8231A		Units
			Min.	Max.	Min.	Max.	Min.	Max.	
t_{AR}	A_0, $\overline{CS}$ Setup to $\overline{RD}$		0		0		0		ns
t_{RA}	A_0, $\overline{CS}$ Hold from $\overline{RD}$		0		0		0		ns
t_{RY}	READY ↓ from $\overline{RD}$ ↓ Delay (Note 2)			150		100		100	ns
t_{YR}	READY ↑ to $\overline{RD}$ ↑		0		0		0		ns
t_{RRR}	READY Pulse Width (Note 3)	Data	3.5 t_{CY} + 50		3.5 t_{CY} + 50		3.5 t_{CY} + 50		ns
		Status	1.5 t_{CY} + 50		1.5 t_{CY} + 50		1.5 t_{CY} + 50		ns
t_{RDE}	Data Bus Enable from $\overline{RD}$ ↓		50		50		50		ns
t_{DRY}	Data Valid to READY ↑		0		0		0		ns
t_{DF}	Data Float after $\overline{RD}$ ↑		50	200	50	150	50	100	ns

WRITE OPERATION

Symbol	Parameter		8231A-8		8231A-3		8231A		Units
			Min.	Max.	Min.	Max.	Min.	Max.	
t_{AW}	A_0, $\overline{CS}$ Setup to $\overline{WR}$		0		0		0		ns
t_{WA}	A_0, $\overline{CS}$ Hold after $\overline{WR}$		[illegible]		30		25		ns
t_{WY}	READY ↓ from $\overline{WR}$ ↓ Delay (Note 2)			150		100		100	ns
t_{YW}	READY ↑ to $\overline{WR}$ ↑		0		0		0		ns
t_{RRW}	READY Pulse Width (Note 4)			50		[illegible]		50	ns
t_{WI}	Write Inactive Time (Note 4)	Command	4 t_{CY}		4 t_{CY}		4 t_{CY}		ns
		Data	5 t_{CY}		5 t_{CY}		5 t_{CY}		ns
t_{DW}	Data Setup to $\overline{WR}$		150		100		100		ns
t_{WD}	Data Hold after $\overline{WR}$		20		20		20		ns

OTHER TIMINGS

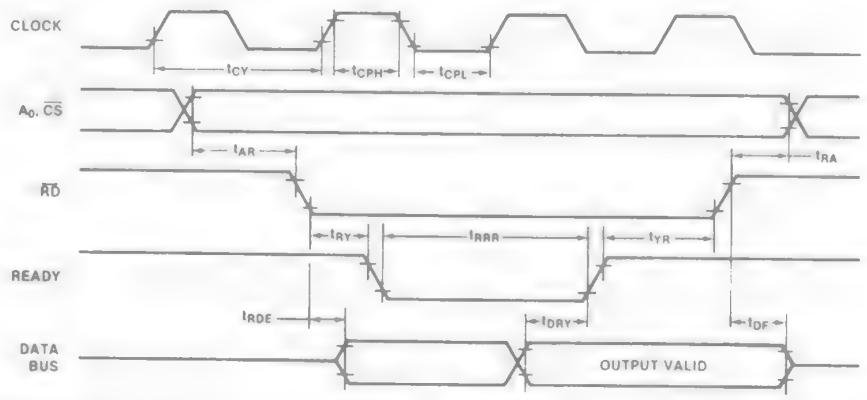
Symbol	Parameter	8231A-8		8231A-3		8231A		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{CY}	Clock Period	480	5000	320	3300	250	2500	ns
t_{CPH}	Clock Pulse High Width	200		140		100		ns
t_{CPL}	Clock Pulse Low Width	240		160		120		ns
t_{EE}	$\overline{END}$ Pulse Width (Note 5)	400		300		200		ns
t_{EAE}	$\overline{EACK}$ ↓ to $\overline{END}$ ↑ Delay		200		175		150	ns
t_{AA}	$\overline{EACK}$ Pulse Width	100		75		50		ns
t_{SA}	$\overline{SVACK}$ ↓ to SVREQ ↓ Delay		300		200		150	ns
t_{SS}	$\overline{SVACK}$ Pulse Width	100		75		50		ns

NOTES:

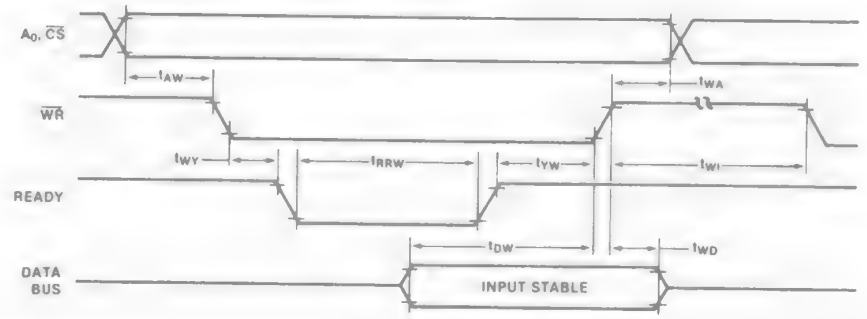
1. Typical values are for T_A=25°C, nominal supply voltages and nominal processing parameters.
2. READY is pulled low for both command and data operations.
3. Minimum values shown assume no previously entered command is being executed for the data access. If a previously entered command is being executed, READY low pulse width is the time to complete execution plus the time shown. Status may be read at any time without exceeding the time shown.
4. READY low pulse width is less than 50 ns when writing into the data port or the control port as long as the duty cycle requirement (t_{WI}) is observed and no previous command is being executed. t_{WI} may be safely violated as long as the extended t_{RRW} that results is observed. If a previously entered command is being executed, READY low pulse width is the time to complete execution plus the time shown. These timings refer specifically to the 8231A.
5. $\overline{END}$ low pulse width is specified for $\overline{EACK}$ tied to VSS. Otherwise t_{EAE} applies.

WAVEFORMS

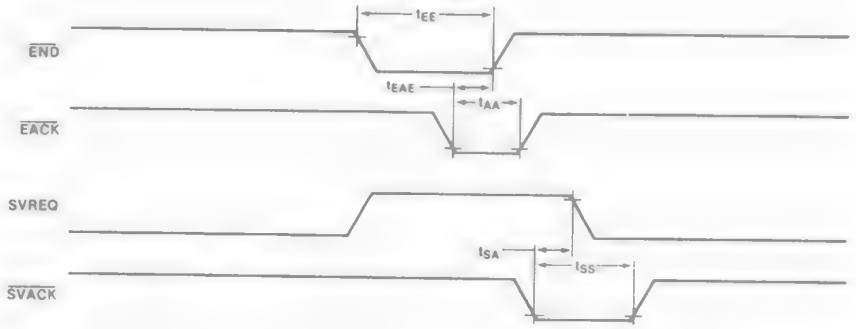
READ OPERATION



WRITE OPERATION



INTERRUPT OPERATION



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PRELIMINARY

8232
FLOATING POINT PROCESSING UNIT

- **Compatible with Proposed IEEE Format and Existing Intel Floating Point Standard**
- **Single (32-Bit) and Double (64-Bit) Precision Capability**
- **Add, Subtract, Multiply and Divide Functions**
- **Stack Oriented Operand Storage**
- **General Purpose 8-Bit Data Bus Interface**
- **Standard 24-Pin Package**
- **12V and 5V Power Supplies**
- **Compatible with MCS-80™, MCS-85™ and MCS-86™ Microprocessor Families**
- **Error Interrupt**
- **Direct Memory Access or Programmed I/O Data Transfers**
- **End of Execution Signal**
- **Advanced N-Channel Silicon Gate HMOS Technology**

The Intel® 8232 is a high performance floating-point processor unit (FPU). It provides single precision (32-bit) and double precision (64-bit) add, subtract, multiply and divide operations. The 8232's floating point arithmetic is a subset of the proposed IEEE standard. It can be easily interfaced to enhance the computational capabilities of the host microprocessor.

The operand, result, status and command information transfers take place over an 8-bit bidirectional data bus. Operands are pushed onto an internal stack by the host processor and a command is issued to perform an operation on the data stack. The results of the operation are available to the host processor from the stack.

Information transfers between the 8232 and the host processor can be handled by using programmed I/O or direct memory access techniques. After completing an operation, the 8232 activates an "end of execution" signal that can be used to interrupt the host processor.

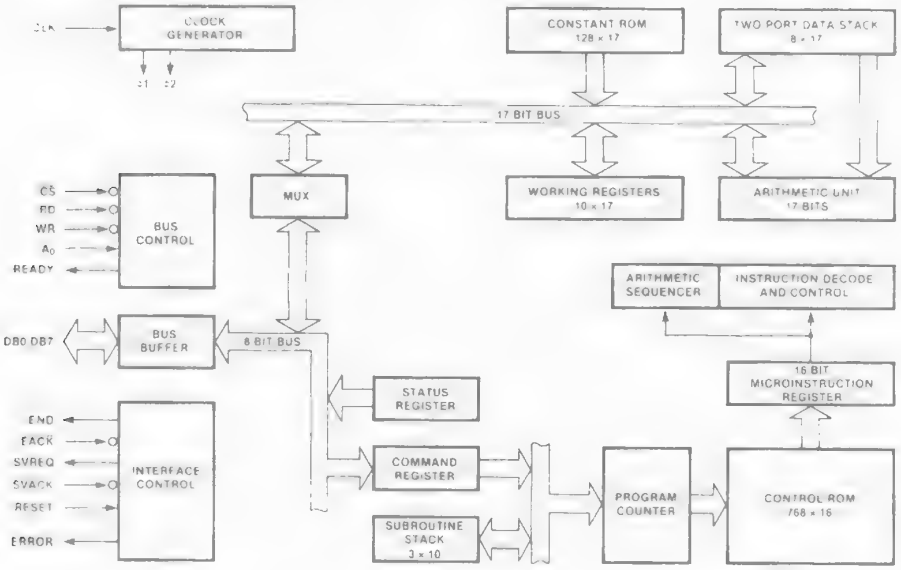


Figure 1. Block Diagram

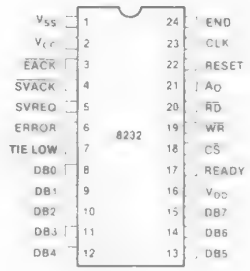


Figure 2. Pin Configuration

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Description
V_{CC}	2		**POWER SUPPLY:** +5V power supply
V_{DD}	16		**POWER SUPPLY:** +12V power supply
V_{SS}	1		**GROUND**
CLK	23	I	**CLOCK:** An external timing source connected to the CLK input provides the necessary clocking.
RESET	22	I	**RESET:** A HIGH level on this input causes initialization. Reset terminates any operation in progress, and clears the status register to zero. The internal stack pointer is initialized and the contents of the stack may be affected. After a reset the END output, the ERROR output and the SVREQ output will be LOW. For proper initialization, RESET must be HIGH for at least five CLK periods following stable power supply voltages and stable clock.
$\overline{CS}$	18	I	**CHIP SELECT:** input must be LOW to accomplish any read or write operation to the 8232. To perform a write operation, appropriate data is presented on DB0 through DB7 lines, appropriate logic level on the A_0 input and the $\overline{CS}$ input is made LOW. Whenever $\overline{WR}$ and $\overline{RD}$ inputs are both HIGH and $\overline{CS}$ is LOW, READY goes LOW. However, actual writing into the 8232 cannot start until $\overline{WR}$ is made LOW. After initiating the write operation by the HIGH to LOW transition on the $\overline{WR}$ input, the READY output will go HIGH, indicating the write operation has been acknowledged. The $\overline{WR}$ input can go HIGH after READY goes HIGH. The data lines, the A_0 input and the $\overline{CS}$ input can change when appropriate hold time requirements are satisfied. See write timing diagram for details. To perform a read operation an appropriate logic level is established on the A_0 input and $\overline{CS}$ is made LOW. The READY output goes LOW because $\overline{WR}$ and $\overline{RD}$ inputs are HIGH. The read operation does not start until the $\overline{RD}$ input goes LOW. READY will go HIGH indicating that read operation is complete and the required information is available on the DB0 through DB7 lines. This information will remain on the data lines as long as $\overline{RD}$ is LOW. The $\overline{RD}$ input can return HIGH anytime after READY goes HIGH. The $\overline{CS}$ input and A_0 input can change anytime after $\overline{RD}$ returns HIGH. See read timing diagram for details. If the $\overline{CS}$ is tied LOW permanently, READY will remain LOW until the next 8232 read or write access.
A_0	21	I	**ADDRESS:** The A_0 input together with the $\overline{RD}$ and $\overline{WR}$ inputs determines the type of transfer to be performed on the data bus as follows: A_0 / $\overline{RD}$ / $\overline{WR}$ / Function 0 / 1 / 0 / Enter data byte into stack 0 / 0 / 1 / Read data byte from stack 1 / 1 / 0 / Enter command 1 / 0 / 1 / Read status
$\overline{RD}$	20	I	**READ:** A LOW level on this input is used to read information from an internal location and gate that information onto the data bus. The $\overline{CS}$ input must be LOW to accomplish the read operation. The A_0 input determines what internal location is to be read. See A_0, $\overline{CS}$ input descriptions and read timing diagram for details. If the END output was HIGH, performing any read operation will make the END output go LOW after the HIGH to LOW transition of the $\overline{RD}$ input (assuming $\overline{CS}$ is LOW). If the ERROR output was HIGH, performing a status register read operation will make the ERROR output LOW. This will happen after the HIGH to LOW transition of the $\overline{RD}$ input (assuming $\overline{CS}$ is LOW).
$\overline{WR}$	19	I	**WRITE:** A LOW level on this input is used to transfer information from the data bus into an internal location. The $\overline{CS}$ must be LOW to accomplish the write operation. A_0 determines which internal location is to be written. See A_0, $\overline{CS}$ input descriptions and write timing diagram for details. If the END output was HIGH, performing any write operation will make the END output go LOW after the LOW to HIGH transition of the $\overline{WR}$ input (assuming $\overline{CS}$ is LOW).
$\overline{EACK}$	3	I	**END ACKNOWLEDGE:** When LOW, makes the END output go LOW. As mentioned earlier, HIGH on the END output signals completion of a command execution. The END signal is derived from an internal flip-flop which is clocked at the completion of a command. This flip-flop is clocked to the reset state when $\overline{EACK}$ is LOW. Consequently, if $\overline{EACK}$ is tied LOW, the END output will be a pulse that is approximately one CLK period wide.
$\overline{SVACK}$	4	I	**SERVICE ACKNOWLEDGE:** A LOW level on this input clears SVREQ. If the $\overline{SVACK}$ input is permanently tied LOW, it will conflict with the internal setting of the SVREQ output. Thus, the SVREQ indication cannot be relied upon if the $\overline{SVACK}$ is tied LOW.
END	24	O	**END OF EXECUTION:** A HIGH on this output indicates that execution of the current command is complete. This output will be cleared LOW by activating the $\overline{EACK}$ input LOW or performing any read or write operation or device initialization using RESET. If $\overline{EACK}$ is tied LOW, the END output will be a pulse (see $\overline{EACK}$ description). Reading the status register while a command execution is in progress is allowed. However, any read or write operation clears the flip-flop that generates the END output. Thus, such continuous reading could conflict with internal logic setting of the END flip-flop at the end of command execution.

Table 1. Pin Description (Continued)

Symbol	Pin No.	Type	Name and Description
SVREQ	5	O	**SERVICE REQUEST:** A HIGH on this output indicates completion of a command. In this sense this output is the same as the END output. However, the SVREQ output will go HIGH at the completion of a command only when the Service Request Enable bit was set to 1. The SVREQ can be cleared (i.e., go LOW) by activating the $\overline{SVACK}$ input LOW or initializing the device using the RESET. Also, the SVREQ will be automatically cleared after completion of any command that has the service request bit as 0.
ERROR	6	O	**ERROR:** Output goes HIGH to indicate that the current command execution resulted in an error condition. The error conditions are: attempt to divide by zero, exponent overflow and exponent underflow. The ERROR output is cleared LOW on a status register read operation or upon RESET. The ERROR output is derived from the error bits in the status register. These error bits will be updated internally at an appropriate time during a command execution. Thus, ERROR output going HIGH may not coincide with the completion of a command. Reading of the status register can be performed while a command execution is in progress. However, it should be noted that reading the status register clears the ERROR output. Thus, reading the status register while a command execution is in progress may result in an internal conflict with the ERROR output.
READY	17	O	**READY:** Output is a handshake signal used while performing read or write transactions with the 8232. If the $\overline{WR}$ and $\overline{RD}$ inputs are both HIGH, the READY output goes LOW with the $\overline{CS}$ input in anticipation of a transaction. If $\overline{WR}$ goes LOW to initiate a write transaction with proper signals established on the DB0–DB7, A_0 inputs, the READY will return HIGH indicating that the write operation has been accomplished. The $\overline{WR}$ can be made HIGH after this event. On the other hand, if a read operation is desired, the $\overline{RD}$ input is made LOW after activating $\overline{CS}$ LOW and establishing proper A_0 input. (The READY will go LOW in response to $\overline{CS}$ going LOW.) The READY will return HIGH, indicating completion of read. The $\overline{RD}$ can return HIGH after this event. It should be noted that a read or write operation can be initiated without any regard to whether a command execution is in progress or not. Proper device operation is assured by obeying the READY output indication as described.
DB0–DB7	8–15	I/O	**DATA BUS:** Bidirectional lines are used to transfer command, status and operand information between the device and the host processor. DB0 is the least significant and DB7 is the most significant bit position. HIGH on a data bus line corresponds to 1 and LOW corresponds to 0. When pushing operands on the stack using the data bus, the least significant byte must be pushed first and the most significant byte last. When popping the stack to read the result of an operation, the most significant byte will be available on the data bus first and the least significant byte will be the last. Moreover, for pushing operands and popping results, the number of transactions must be equal to the proper number of bytes appropriate for the chosen format. Otherwise, the internal byte pointer will not be aligned properly. The single precision format requires 4 bytes and double precision format requires 8 bytes.

FUNCTIONAL DESCRIPTION

Major functional units of the 8232 are shown in the block diagram. The 8232 employs a microprogram controlled stack oriented architecture with 17-bit wide data paths.

The Arithmetic Unit receives one of its operands from the Operand Stack. This stack is an eight word by 17-bit two port memory with last in-first out (LIFO) attributes. The second operand to the Arithmetic Unit is supplied by the internal 17-bit bus. In addition to supplying the second operand, this bidirectional bus also carries the results from the output of the Arithmetic Unit when required. Writing into the Operand Stack takes place from this internal 17-bit bus when required. Also connected to this bus are the Constant ROM and Working Registers. The ROM provides the required constants to perform the mathematical operations while the Working Registers provide storage for the intermediate values during command execution.

Communication between the external world and the 8232 takes place on eight bidirectional input/output lines, DB0 through DB7 (Data Bus). These signals are gated to the internal 8-bit bus through appropriate interface and buffer circuitry. Multiplexing facilities exist for bidirectional communication between the internal eight

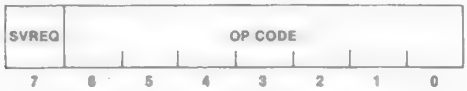
and 17-bit buses. The Status Register and Command Register are also located on the 8-bit bus.

The 8232 operations are controlled by the microprogram contained in the Control ROM. The Program Counter supplies the microprogram addresses and can be partially loaded from the Command Register. Associated with the Program Counter is the Subroutine Stack where return addresses are held during subroutine calls in the microprogram. The Microinstruction Register holds the current microinstruction being executed. The register facilitates pipelined microprogram execution. The Instruction Decode logic generates various internal control signals needed for the 8232 operation.

The Interface Control logic receives several external inputs and provides handshake related outputs to facilitate interfacing the 8232 to microprocessors.

Command Format

The operation of the 8232 is controlled from the host processor by issuing instructions called commands. The command format is shown below.



The command consists of 8 bits; the least significant 7 bits specify the operation to be performed as detailed in Table 1. The most significant bit is the Service Request Enable bit. This bit must be a 1 if SVREQ is to go HIGH at the end of executing a command.

The commands fall into three categories: single precision arithmetic, double precision arithmetic and data manipulation. There are four arithmetic operations that can be performed with single precision (32-bit) or double precision (64-bit) floating-point numbers: add, subtract, multiply and divide. These operations require two operands. The 8232 assumes that these operands are located in the internal stack as Top of Stack (TOS) and Next on Stack (NOS). The result will always be returned to the previous NOS which becomes the new TOS. Results from an operation are of the same precision and format as the operands. The results will be rounded to preserve the accuracy. The actual data formats and rounding procedures are described in a later section. In addition to the arithmetic operations, the 8232 implements eight data manipulating operations. These include changing the sign of a double or single precision operand located in TOS, exchanging single precision operands located at TOS and NOS, as well as pushing and popping single or double precision operands. See also the sections on status register and operand formats.

The execution times of the commands are all data dependent. Table 3 shows one example of each command execution time.

Operand Entry

The 8232 commands operate on the operands located at the TOS and NOS. Results are returned to the stack at NOS and then popped to TOS. The operands required for the 8232 are one of two formats — single precision floating-point (4 bytes) or double precision floating-point (8 bytes). The result of an operation has the same format as the operands. In other words, operations using single precision quantities always result in a single precision result, while operations involving double precision quantities will result in double precision result.

Operands are always entered into the stack least significant byte first and most significant byte last. The following procedure must be followed to enter operands into the stack:

1. The lower significant operand byte is established on the DB0–DB7 lines.
2. A LOW is established on the A_0 input to specify that data is to be entered into the stack.
3. The $\overline{CS}$ input is made LOW. Whenever the $\overline{WR}$ and $\overline{RD}$ inputs are HIGH, the READY output will follow the $\overline{CS}$ input. Thus, READY output will become LOW.
4. After appropriate set up time (see timing diagrams), the $\overline{WR}$ input is made LOW.
5. Sometime after this event, READY will return HIGH to indicate that the write operation has been acknowledged.
6. Any time after the READY output goes HIGH, the $\overline{WR}$ input can be made HIGH. The DB0–DB7, A_0 and $\overline{CS}$ inputs can change after appropriate hold time requirements are satisfied (see timing diagrams).

The above procedure must be repeated until all bytes of the operand are pushed into the stack. It should be noted that for single precision operands 4 bytes should be pushed and 8 bytes must be pushed for double precision. Not pushing all the bytes of a quantity will result in byte pointer misalignment.

The 8232 stack can accommodate four single precision quantities or two double precision quantities. Pushing more quantities than the capacity of the stack will result in loss of data which is usual with any LIFO stack.

The stack can be visualized as shown below:

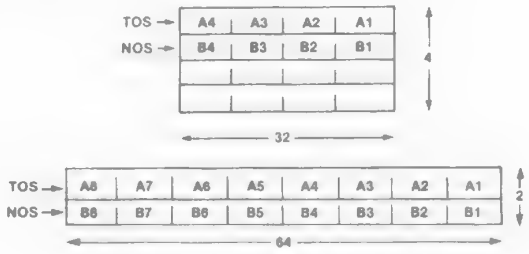


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Table 2. 8232 Command Set

Single Precision Instructions

Instruction	Description	Hex[1] Code	Stack Contents[2] After Execution A	B	C	D	Status Flags Affected[4]
SADD	Add A and B	01	R	C	D	U	S, Z, U, V
SSUB	Subtract A from B	02	R	C	D	U	S, Z, U, V
SMUL	Multiply A by B	03	R	C	D	U	S, Z, U, V
SDIV	Divide B by A. If A exponent = 0, then R = B.	04	R	C	D	U	S, Z, U, V, D
CHSS	Change sign of A[5]	05	R	B	C	D	S, Z
PTOS	Push stack[5]	06	A*	A	B	C	S, Z
POPS	Pop stack	07	B	C	D	A	S, Z
XCHS	Exchange	[illegible]	B	A	C	D	S, Z

Double Precision Instructions

Instruction	Description	Hex[1] Code	Stack Contents[3] After Execution A	B	Status Flags Affected[4]
DADD	Add A and B	29	R	U	S, Z, U, V
DSUB	Subtract A from B	2A	R	U	S, Z, U, V
DMUL	Multiply A by B	2B	R	U	S, Z, U, V
DDIV	Divide B by A. If A = 0, then R = B.	2C	R	U	S, Z, U, V, D
CHSD	Change sign of A[5]	2D	R	B	S, Z
PTOD	Push stack[5]	2E	A*	A	S, Z
POPD	Pop stack	2F	B	A	S, Z
CLR	CLR status	00	A	B	

Notes:

1. In the hex code column, SVREQ bit is a 0.
2. The stack initially is composed of four 32-bit numbers (A, B, C, D). A is equivalent to Top Of Stack (TOS) and B is Next on Stack (NOS). Upon completion of a command the stack is composed of: the result (R); undefined (U); or the initial contents (A,B,C, or D).
3. The stack initially is composed of two 64-bit numbers (A, B). A is equivalent to Top Of Stack (TOS) and B is Next On Stack (NOS). Upon completion of a command the stack is composed of: the result (R); undefined (U); or the initial contents (A, B).
4. Any status bit(s) not affected are set to 0. Nomenclature: Sign (S); Zero (Z); Exponent Underflow (U); Exponent Overflow (V); Divide Exception (D)
5. If the exponent field of A is zero, R or A* will be zero.

Table 3. Execution Times

Command	TOS	NOS	Result	Clock Periods
SADD	3F800000	3F800000	40000000	[illegible]
SSUB	3F800000	3F800000	00000000	56
SMUL	40400000	3FC00000	40900000	198
SDIV	3F800000	40000000	3F000000	228
CHSS	3F800000	—	BF800000	10
PTOS	3F800000	—	—	16
POPS	3F800000	—	—	14
XCHS	3F800000	40000000	—	26
CHSD	3FF00000 00000000	—	BFF00000 00000000	24
PTOD	3FF00000 00000000	—	—	40
POPD	3FF00000 00000000	—	—	26
CLR	3FF00000 00000000	—	—	4
DADD	3FF00000 0A000000	3FF00000 00000000	3FF00000 0A000000	578
DSUB	3FF00000 A0000000	3FF00000 00000000	3FF00000 A0000000	578
DMUL	BFF80000 00000000	3FF80000 00000000	C0020000 00000000	1748
DDIV	BFF80000 00000000	3FF80000 00000000	BFF00000 00000000	4560

Note: TOS, NOS and result are in hexadecimal; clock period is in decimal.

Command Initiation

After properly positioning the required operands in the stack, a command may be issued. The procedure for initiating a command execution is the same as that described above for operand entry, except that the A_0 input is HIGH.

An attempt to issue a new command while the current command execution is in progress is allowed. Under these circumstances, the READY output will not go HIGH until the current command execution is completed.

Removing the Results

Result from an operation will be available at the TOS. Results can be transferred from the stack to the data bus by reading the stack.

When the stack is read for results, the most significant byte is available first and the least significant byte last.

A result is always of the same precision as the operands that produced it. Thus, when the result is taken from the stack, the total number of bytes popped out should be appropriate with the precision — single precision results are 4 bytes and double precision results are 8 bytes. The following procedure must be used for reading the result from the stack:

1. A LOW is established on the A_0 input.
2. The $\overline{CS}$ input is made LOW. When $\overline{WR}$ and $\overline{RD}$ inputs are both HIGH, the READY output follows the $\overline{CS}$ input, thus READY will be LOW.
3. After appropriate set up time (see timing diagrams), the $\overline{RD}$ input is made LOW.
4. Sometime after this, READY will return HIGH, indicating that the data is available on the DB0–DB7 lines. This data will remain on the DB0–DB7 lines as long as the $\overline{RD}$ input remains LOW.
5. Any time after READY goes HIGH, the $\overline{RD}$ input can return HIGH to complete the transaction.
6. The $\overline{CS}$ and A_0 inputs can change after appropriate hold time requirements are satisfied (see timing diagram).
7. Repeat this procedure until all bytes appropriate for the precision of the result are popped out.

Reading of the stack does not alter its data; it only adjusts the byte pointer. Note data must be removed in even byte multiples to avoid a byte pointer misalignment. If more data is popped than the capacity of the stack, the internal byte pointer will wrap around and older data will be read again, consistent with the LIFO stack.

Reading Status Register

The 8232 status register can be read without any regard to whether a command is in progress or not. The only implication that has to be considered is the effect this might have on the END and ERROR outputs discussed in the signal descriptions.

The following procedure must be followed to accomplish status register reading:

1. Establish HIGH on the A_0 input.
2. Establish LOW on the $\overline{CS}$ input. Whenever $\overline{WR}$ and $\overline{RD}$ inputs are HIGH, READY will follow the $\overline{CS}$ input. Thus, READY will go LOW.
3. After appropriate set up time (see timing diagram), $\overline{RD}$ is made LOW.

4. Sometime after the HIGH to LOW transition of $\overline{RD}$, READY will become HIGH, indicating that status register contents are available on the DB0-DB7 lines. These lines will contain this information as long as $\overline{RD}$ is LOW.
5. The $\overline{RD}$ input can be returned HIGH any time after READY goes HIGH.
6. The A_0 input and $\overline{CS}$ input can change after satisfying appropriate hold time requirements (see timing diagram).

Status Register

The 8232 contains an 8-bit status register with the following format:

BUSY	SIGN S	ZERO Z	RESERVED	DIVIDE EXCEPTION D	EXPONENT UNDERFLOW U	EXPONENT OVERFLOW V	RESERVED
7	6	5	4	3	2	1	0

All the bits are initialized to zero upon reset. Also, executing a CLR (Clear Status) command will result in all zero status register bits. A zero in bit 7 indicates that the 8232 is not busy and a new command may be initiated. As soon as a new command is issued, bit 7 becomes 1 to indicate the device is busy and remains 1 until the command execution is complete, at which time it will become 0. As soon as a new command is issued, status register bits 0-6 are cleared to zero. The status bits will be set as required during the command execution. Hence, as long as bit 7 is 1, the remainder of the status register bit indications should not be relied upon unless the ERROR occurs. The following is a detailed status bit description.

Bit 0 Reserved.

Bit 1 Exponent overflow (V). When 1, this bit indicates that the result exponent is more positive than +127 (+1023). The exponent is "wrapped" into the negative exponent range, skipping the end values.

Bit 2 Exponent Underflow (U). When 1, this bit indicates that the result exponent is more negative than −126 (−1022). The exponent is "wrapped" into the positive range by the number of underflow bits, skipping −127 (−1023) and +128 (+1024).

Bit 3 Divide Exception (D). When 1, this bit indicates that an attempt to divide by zero is made. Cleared to zero otherwise.

Bit 4 Reserved.

Bit 5 Zero (Z). When 1, this bit indicates that the result returned to TOS after a command is zero. Cleared to zero otherwise.

Bit 6 Sign (S). When 1, this bit indicates that the result returned to TOS is negative. Cleared to zero otherwise.

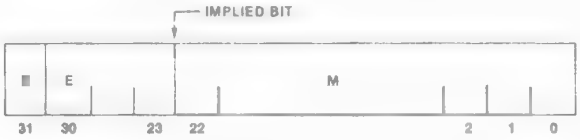
Bit 7 Busy. When 1, this bit indicates the 8232 is in the process of executing a command. It will become zero after the command execution is complete.

All other status register bits are valid when the Busy bit is zero.

Data Formats

The 8232 handles floating-point quantities in two different formats — single precision and double precision. These formats are the same as those used by Intel in other products and those proposed by the IEEE Subcommittee on floating point arithmetic.

The single precision quantities are 32 bits long, as shown below:



Bit 31:

S = Sign of the mantissa. One represents negative and 0 represents positive.

Bits 23-30:

E = These 8 bits represent a biased exponent. The bias is $2^7 - 1 = 127$.

Bits 0-22:

M = 23-bit mantissa. Together with the sign bit, the mantissa represents a signed fraction in sign-magnitude notation. There is an implied 1 beyond the most significant bit (bit 22) of the mantissa. In other words, the mantissa is assumed to be a 24-bit normalized quantity and the most significant bit, which will always be a 1 due to normalization, is implied. The 8232 restores this implied bit internally before performing arithmetic, normalizes the result and strips the implied bit before returning the results to the external data bus. The binary point is between the implied bit and bit 22 of the mantissa.

The quantity N represented by the above notation is

$$N = (-1)^S \, 2^{E-\overbrace{(2^7-1)}^{\text{BIAS}}} \, (1.M)$$

BINARY POINT

Provided E≠0 (reserved for 0) or all 1's (illegal). The approximate decimal range for this format is $\pm 1.17 \times 10^{-38}$ to $\pm 3.40 \times 10^{38}$. The format supports 7 significant decimal digits.

A double precision quantity consists of the mantissa sign bit, an 11-bit biased exponent (E), and a 52-bit mantissa (M). The bias for double precision quantities is $2^{10} - 1$. The double precision format is illustrated below.

Bit 63:

S = Sign of the mantissa. One represents negative and 0 represents positive.

Bits 52-62:

E = These 11 bits represent a biased exponent. The bias is $2^{10} - 1 = 1023$.

Bits 0-51:

M = 52-bit mantissa. Together with the sign bit the mantissa represents a signed fraction in sign-magnitude notation. There is an implied 1 beyond the most significant bit (bit 51) of the mantissa. In other words, the mantissa is assumed to be a 53-bit normalized quantity and the most significant bit, which will always be a 1 due to normalization, is implied. The 8232 restores this implied bit internally before performing arithmetic, normalizes the result and strips the implied bit before returning the result to the external data bus. The binary point is between the implied bit and bit 51 of the mantissa.

The quantity N represented by the above notation is

$$N = (-1)^S \, 2^{E - \overbrace{(2^{10} - 1)}^{\text{BIAS}}} \, (1.M)$$

BINARY POINT

Provided E ≠ 0 (reserved for 0) or all 1s (illegal). The approximate decimal range is $\pm 2.22 \times 10^{-308}$ to $\pm 1.80 \times 10^{308}$. The format supports 16 significant decimal digits.

The following are some examples of single precision floating point representations:

Decimal	S	E	M	Binary Floating Point
0	0	0	0	0000 0000H
1	0	127	0	3F80 0000H
−1	1	127	0	BF80 0000H
255	0	134	.9922	437F 0000H
π	0	128	.5708	4049 0FDBH

Rounding

One of the main objectives in choosing the 8232's Intel/IEEE proposed floating point arithmetic was to provide maximum accuracy with no anomalies. This means that a mathematically unsophisticated user will not be "surprised" by some of the results. It is probably possible for a sophisticated user to obtain reliable results from almost any floating point arithmetic. However, in that case there will be an additional burden on the software.

The best example of what might be called the 8232's "safety factor" is the inclusion of guard bits for rounding. The absence of guard bits leads to the problem demonstrated by the following four-bit multiplication:

$$\begin{array}{l} .1111 \times 2^0 \\ .1000 \times 2^1 \\ \hline .01111000 \times 2^1 \end{array}$$

Since the last four bits are lost, the normalized result is:

$$.1110 \times 2^0$$

and the identify function is not valid. In the past this problem has been avoided (hopefully) by relying on excess precision.

Instead the 8232 uses a form of rounding known as "round to even." There are other types of rounding provided for in the proposed IEEE standard, but "round to even," an unbiased rounding scheme, is required. "Round to even" comes into play when a result is exactly halfway between two floating point numbers. In this case the arithmetic produces the "even" number, the one whose last mantissa bit is zero. The 8232 uses three additional bits—the Guard bit (G), the Rounding bit (R), and the "Sticky" bit (S)—to do the rounding. These are bits which hold data shifted out (right) of the accumulator. Rounding is carried out by the following rules, as shown in the following figure, after the result is normalized.

G	Bit R	S	Rule
0	0	0	No Round
0	0	1	Round Down
0	1	0	
0	1	1	
1	0	0	Round to Even
1	0	1	Round Up
1	1	0	
1	1	1	

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APPLICATIONS INFORMATION

The diagram in Figure 3 represents the minimum configuration of an 8232 system. The CPU transfers data to and from the 8232 Floating Point Processor using the READY line. The 8232 status is checked using polling by the CPU.

In a high performance configuration (Figure 4), interrupts are used in place of polling. The interrupts are generated for an error condition and to signal the end of execution. Operand transfers are handled by the DMA controller.

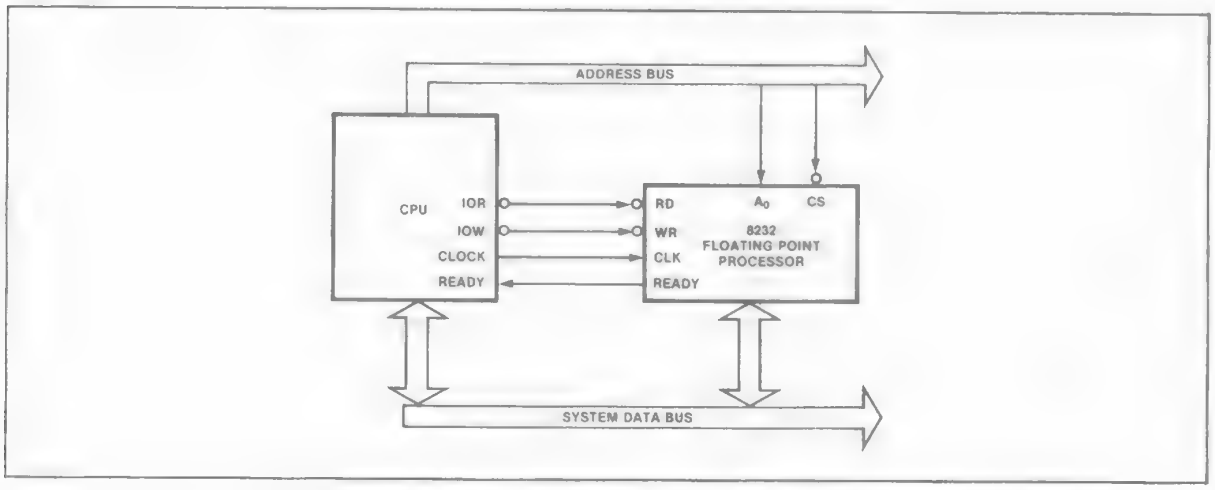

Figure 3. Minimum Configuration Example

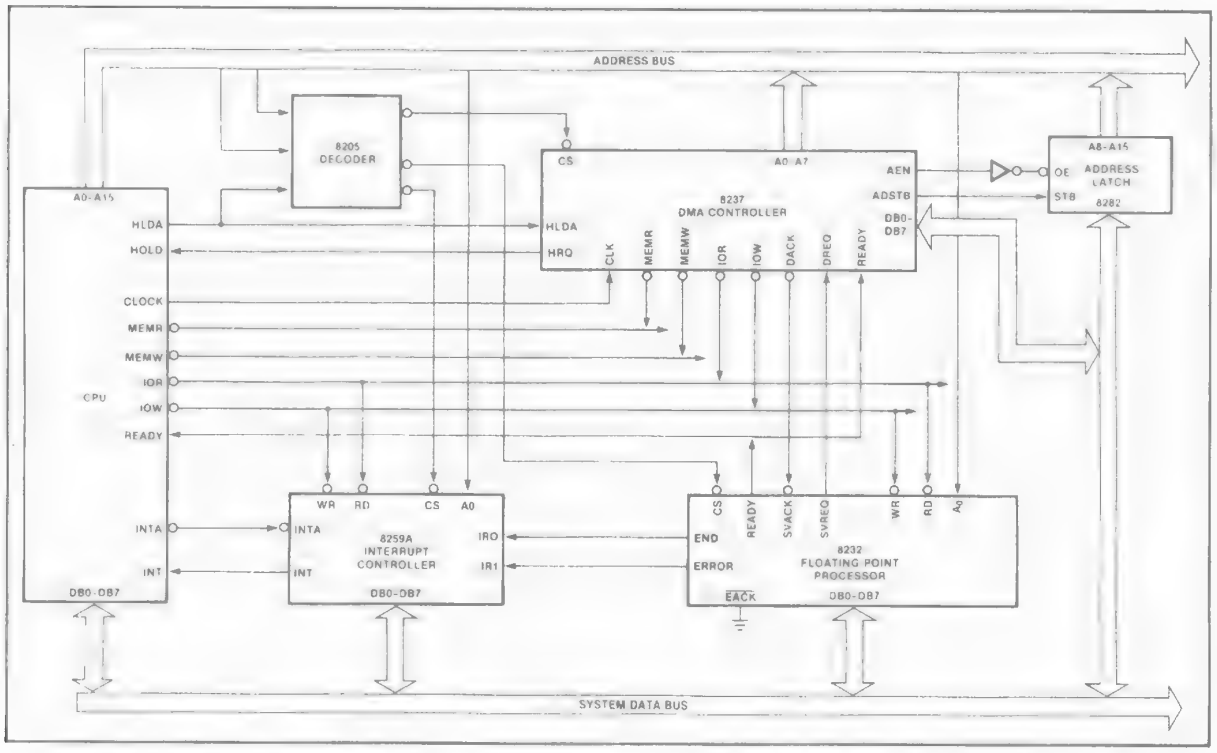

Figure 4. High Performance Configuration Example

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ABSOLUTE MAXIMUM RATINGS*

Storage Temperature . . . . . −65°C to +150°C
Ambient Temperature Under Bias . . . . . 0°C to +70°C
V_{DD} with Respect to V_{SS} . . . . . −0.5V to +15.0V
V_{CC} with Respect to V_{SS} . . . . . −0.5V to +7.0V
All Signal Voltages with Respect to V_{SS} . . . . . −0.5V to +7.0V
Power Dissipation 2.0W

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{SS} = 0V, V_{CC} = +5V ± 10%, V_{DD} = +12V ± 10%)

Symbol	Parameter	Min.	Typ.	Max.	Units	Test Conditions
V_{OH}	Output HIGH Voltage	3.7			V	$I_{OH} = -200\mu A$
V_{OL}	Output LOW Voltage			0.4	V	$I_{OL} = 3.2\,mA$
V_{IH}	Input HIGH Voltage	2.0		V_{CC}	V	
V_{IL}	Input LOW Voltage	−0.5		0.8	V	
I_{IL}	Input Load Current			±10	μA	$V_{SS} \leq V_{IN} \leq V_{CC}$
I_{OFL}	Data Bus Leakage			±10	μA	V_{SS} +0.45 $\leq V_{OUT} \leq V_{CC}$
I_{CC}	V_{CC} Supply Current		50	95	mA	
I_{DD}	V_{DD} Supply Current		50	95	mA	
C_O	Output Capacitance		8		pF	f_C = 1.0 MHz, Inputs = 0V
C_I	Input Capacitance		5		pF	
C_{IO}	I/O Capacitance		10		pF	

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{SS} = 0V, V_{CC} = +5V ± 10%, V_{DD} = +12V ± 10%)

READ OPERATION

Symbol	Parameter		8232		8232-3		8232-8		Units
			Min.	Max.	Min.	Max.	Min.	Max.	
t_{AR}	A_0, $\overline{CS}$ Setup to $\overline{RD}$		0		0		0		ns
t_{RA}	A_0, $\overline{CS}$ Hold from $\overline{RD}$		0		0		0		ns
t_{ARY}	READY↓ from A_0, $\overline{CS}$↓ Delay (Note 2)			100		100		150	ns
t_{YR}	READY↑ to $\overline{RD}$↑		0		0		0		ns
t_{RRR}	READY Pulse Width (Note 3)	Data	3.5 t_{CY} + 50		3.5 t_{CY} + 50		3.5 t_{CY} + 50		ns
		Status	1.5 t_{CY} + 50		1.5 t_{CY} + 50		1.5 t_{CY} + 50		ns
t_{RDE}	Data Bus Enable from $\overline{RD}$↓		50		50		50		ns
t_{DRY}	Data Valid to READY↑		0		0		0		ns
t_{DF}	Data Float after $\overline{RD}$↑		20	100	20	150	20	200	ns

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A.C. CHARACTERISTICS (Continued)

WRITE OPERATION

Symbol	Parameter	8232		8232-3		8232-8		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{AW}	A_0, $\overline{CS}$ Setup to $\overline{WR}$	25		25		25		ns
t_{WA}	A_0, $\overline{CS}$ Hold after $\overline{WR}$	30		30		60		ns
t_{AWY}	READY↓ from A_0, $\overline{CS}$↓ Delay (Note 2)		100		100		150	ns
t_{YW}	READY↑ to $\overline{WR}$↑	0		0		0		ns
t_{RRW}	READY Pulse Width		t_{AW} + 50		t_{AW} + 50		t_{AW} + 50	ns
t_{DW}	Data Setup to $\overline{WR}$↑	100		100		150		ns
t_{WD}	Data Hold after $\overline{WR}$↑	20		20		30		ns

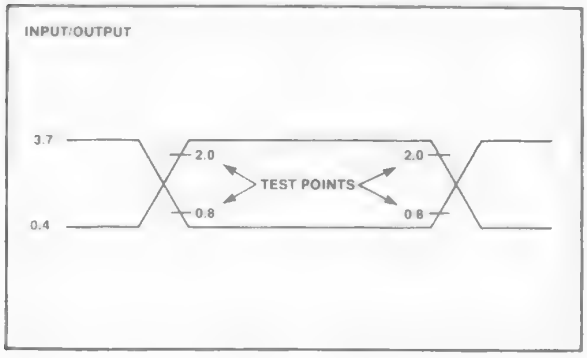
OTHER TIMINGS

Symbol	Parameter	8232		8232-3		8232-8		Units
		Min.	Max.	Min.	Max.	Min.	Max.	
t_{CY}	Clock Period	250	2500	320	3300	480	5000	ns
t_{CPH}	Clock Pulse HIGH Width	100		140		200		ns
t_{CPL}	Clock Pulse LOW Width	120		160		240		ns
t_{EE}	END Pulse Width (Note 4)	200		300		400		ns
t_{EAE}	$\overline{EACK}$↓ to END↓ Delay		150		175		200	ns
t_{AA}	$\overline{EACK}$ Pulse Width	50		75		100		ns
t_{SA}	$\overline{SVACK}$↓ to SVREQ↓ Delay		100		200		300	ns
t_{SS}	$\overline{SVACK}$ Pulse Width	50		75		100		ns

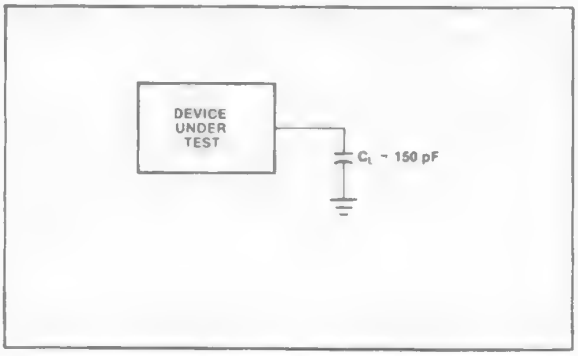
NOTES:

1. Typical values are for $T_A = 25°C$, nominal supply voltages and nominal processing parameters.
2. READY is pulled low for both command and data operations.
3. Minimum values shown assume no previously entered command is being executed for the data access. If a previously entered command is being executed, READY low pulse width is the time to complete execution plus the time shown. Status may be read at any time without exceeding the time shown.
4. END high pulse width is specified for EACK tied to V_{SS}. Otherwise t_{EAE} applies.

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING LOAD CIRCUIT



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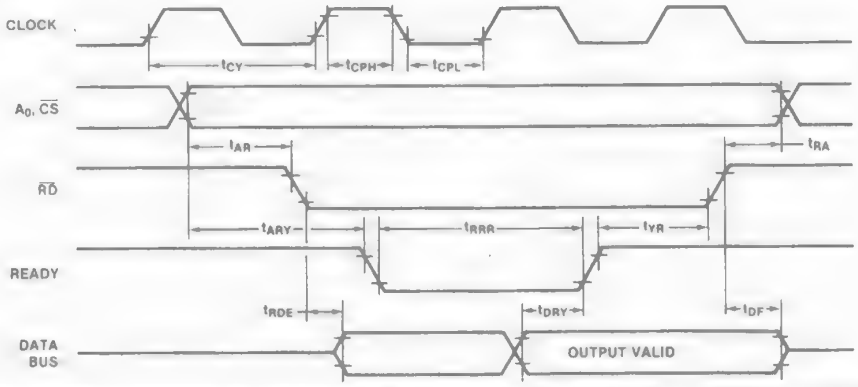
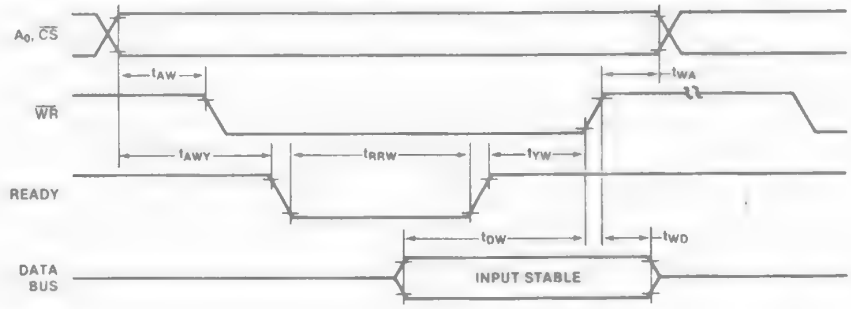
WAVEFORMS

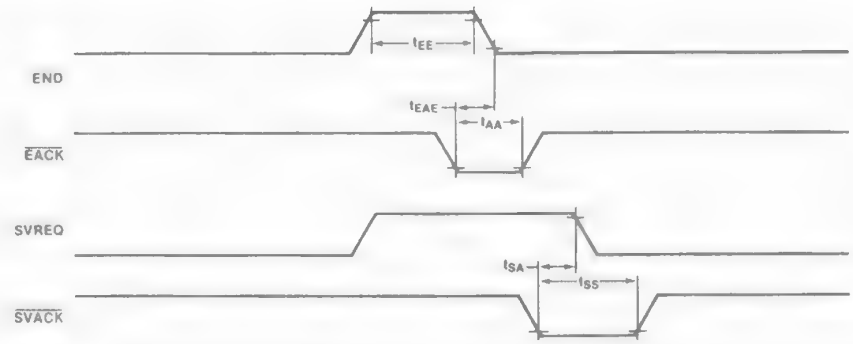
READ OPERATION



WRITE OPERATION



INTERRUPT OPERATION



8251A
PROGRAMMABLE COMMUNICATION INTERFACE

- **Synchronous and Asynchronous Operation**
- **Synchronous 5–8 Bit Characters; Internal or External Character Synchronization; Automatic Sync Insertion**
- **Asynchronous 5–8 Bit Characters; Clock Rate—1, 16 or 64 Times Baud Rate; Break Character Generation; 1, 1½, or 2 Stop Bits; False Start Bit Detection; Automatic Break Detect and Handling**
- **Synchronous Baud Rate—DC to 64K Baud**
- **Asynchronous Baud Rate—DC to 19.2K Baud**
- **Full-Duplex, Double-Buffered Transmitter and Receiver**
- **Error Detection—Parity, Overrun and Framing**
- **Compatible with an Extended Range of Intel Microprocessors**
- **28-Pin DIP Package**
- **All Inputs and Outputs are TTL Compatible**
- **Available in EXPRESS**
  —Standard Temperature Range
  —Extended Temperature Range

The Intel® 8251A is the enhanced version of the industry standard, Intel 8251 Universal Synchronous/Asynchronous Receiver/Transmitter (USART), designed for data communications with Intel's microprocessor families such as MCS-68, 80, 85, and iAPX-86, 88. The 8251A is used as a peripheral device and is programmed by the CPU to operate using virtually any serial data transmission technique presently in use (including IBM "bi-sync"). The USART accepts data characters from the CPU in parallel format and then converts them into a continuous serial data stream for transmission. Simultaneously, it can receive serial data streams and convert them into parallel data characters for the CPU. The USART will signal the CPU whenever it can accept a new character for transmission or whenever it has received a character for the CPU. The CPU can read the complete status of the USART at any time. These include data transmission errors and control signals such as SYNDET, TxEMPTY. The chip is fabricated using N-channel silicon gate technology.

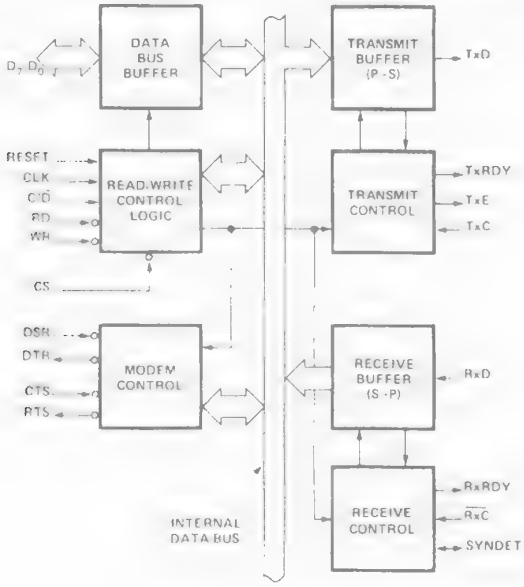


Figure 1. Block Diagram

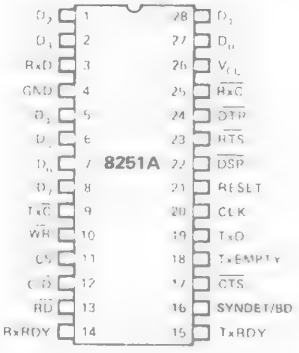


Figure 2. Pin Configuration

*INTEL CORPORATION, 1982

FEATURES AND ENHANCEMENTS

The 8251A is an advanced design of the industry standard USART, the Intel® 8251. The 8251A operates with an extended range of Intel microprocessors and maintains compatibility with the 8251. Familiarization time is minimal because of compatibility and involves only knowing the additional features and enhancements, and reviewing the AC and DC specifications of the 8251A.

The 8251A incorporates all the key features of the 8251 and has the following additional features and enhancements:

- 8251A has double-buffered data paths with separate I/O registers for control, status, Data In, and Data Out, which considerably simplifies control programming and minimizes CPU overhead.
- In asynchronous operations, the Receiver detects and handles "break" automatically, relieving the CPU of this task.
- A refined Rx initialization prevents the Receiver from starting when in "break" state, preventing unwanted interrupts from a disconnected USART.
- At the conclusion of a transmission, TxD line will always return to the marking state unless SBRK is programmed.
- Tx Enable logic enhancement prevents a Tx Disable command from halting transmission until all data previously written has been transmitted. The logic also prevents the transmitter from turning off in the middle of a word.
- When External Sync Detect is programmed, Internal Sync Detect is disabled, and an External Sync Detect status is provided via a flip-flop which clears itself upon a status read.
- Possibility of false sync detect is minimized by ensuring that if double character sync is programmed, the characters be contiguously detected and also by clearing the Rx register to all ones whenever Enter Hunt command is issued in Sync mode.
- As long as the 8251A is not selected, the $\overline{RD}$ and $\overline{WR}$ do not affect the internal operation of the device.
- The 8251A Status can be read at any time but the status update will be inhibited during status read.
- The 8251A is free from extraneous glitches and has enhanced AC and DC characteristics, providing higher speed and better operating margins.
- Synchronous Baud rate from DC to 64K.

FUNCTIONAL DESCRIPTION

General

The 8251A is a Universal Synchronous/Asynchronous Receiver/Transmitter designed for a wide range of Intel microcomputers such as 8048, 8080, 8085, 8086 and 8088. Like other I/O devices in a microcomputer system, its functional configuration is programmed by the system's software for maximum flexibility. The 8251A can support most serial data techniques in use, including IBM "bi-sync."

In a communication environment an interface device must convert parallel format system data into serial format for transmission and convert incoming serial format data into parallel system data for reception. The interface device must also delete or insert bits or characters that are functionally unique to the communication technique. In essence, the interface should appear "transparent" to the CPU, a simple input or output of byte-oriented system data.

Data Bus Buffer

This 3-state, bidirectional, 8-bit buffer is used to interface the 8251A to the system Data Bus. Data is transmitted or received by the buffer upon execution of INput or OUTput instructions of the CPU. Control words, Command words and Status information are also transferred through the Data Bus Buffer. The Command Status, Data-In and Data-Out registers are separate, 8-bit registers communicating with the system bus through the Data Bus Buffer.

This functional block accepts inputs from the system Control bus and generates control signals for overall device operation. It contains the Control Word Register and Command Word Register that store the various control formats for the device functional definition.

RESET (Reset)

A "high" on this input forces the 8251A into an "Idle" mode. The device will remain at "Idle" until a new set of control words is written into the 8251A to program its functional definition. Minimum RESET pulse width is 6 t_{CY} (clock must be running).

A command reset operation also puts the device into the "Idle" state.

CLK (Clock)

The CLK input is used to generate internal device timing and is normally connected to the Phase 2 (TTL) output of the Clock Generator. No external inputs or outputs are referenced to CLK but the frequency of CLK must be greater than 30 times the Receiver or Transmitter data bit rates.

$\overline{WR}$ (Write)

A "low" on this input informs the 8251A that the CPU is writing data or control words to the 8251A.

$\overline{RD}$ (Read)

A "low" on this input informs the 8251A that the CPU is reading data or status information from the 8251A.

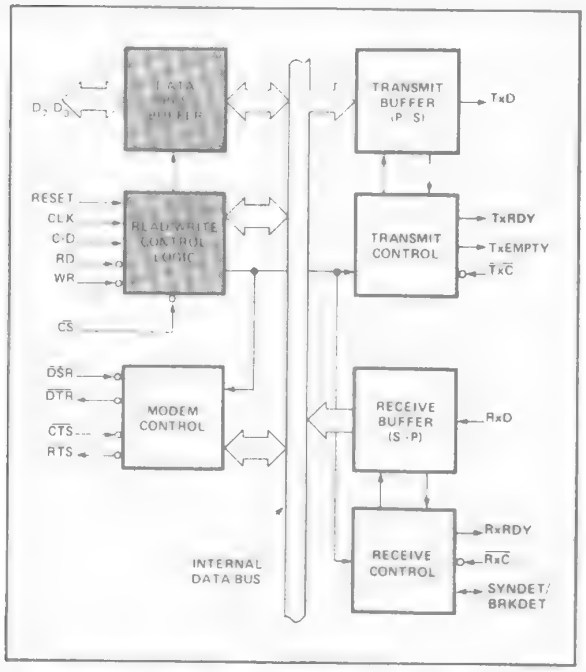


Figure 3. 8251A Block Diagram Showing Data Bus Buffer and Read/Write Logic Functions

C/$\overline{D}$	$\overline{RD}$	$\overline{WR}$	$\overline{CS}$	
0	0	1	0	8251A DATA → DATA BUS
0	1	0	0	DATA BUS → 8251A DATA
1	0	1	0	STATUS → DATA BUS
1	1	0	0	DATA BUS → CONTROL
X	1	1	0	DATA BUS → 3-STATE
X	X	X	1	DATA BUS → 3-STATE

C/$\overline{D}$ (Control/Data)

This input, in conjunction with the $\overline{WR}$ and $\overline{RD}$ inputs, informs the 8251A that the word on the Data Bus is either a data character, control word or status information.

1 = CONTROL/STATUS; 0 = DATA.

$\overline{CS}$ (Chip Select)

A "low" on this input selects the 8251A. No reading or writing will occur unless the device is selected. When $\overline{CS}$ is high, the Data Bus is in the float state and $\overline{RD}$ and $\overline{WR}$ have no effect on the chip.

Modem Control

The 8251A has a set of control inputs and outputs that can be used to simplify the interface to almost any modem. The modem control signals are general purpose in nature and can be used for functions other than modem control, if necessary.

$\overline{DSR}$ (Data Set Ready)

The $\overline{DSR}$ input signal is a general-purpose, 1-bit inverting input port. Its condition can be tested by the CPU using a Status Read operation. The $\overline{DSR}$ input is normally used to test modem conditions such as Data Set Ready.

$\overline{DTR}$ (Data Terminal Ready)

The $\overline{DTR}$ output signal is a general-purpose, 1-bit inverting output port. It can be set "low" by programming the appropriate bit in the Command Instruction word. The $\overline{DTR}$ output signal is normally used for modem control such as Data Terminal Ready.

$\overline{RTS}$ (Request to Send)

The $\overline{RTS}$ output signal is a general-purpose, 1-bit inverting output port. It can be set "low" by programming the appropriate bit in the Command Instruction word. The $\overline{RTS}$ output signal is normally used for modem control such as Request to Send.

$\overline{CTS}$ (Clear to Send)

A "low" on this input enables the 8251A to transmit serial data if the Tx Enable bit in the Command byte is set to a "one." If either a Tx Enable off or $\overline{CTS}$ off condition occurs while the Tx is in operation, the Tx will transmit all the data in the USART, written prior to Tx Disable command before shutting down.

Transmitter Buffer

The Transmitter Buffer accepts parallel data from the Data Bus Buffer, converts it to a serial bit stream, inserts the appropriate characters or bits (based on the communication technique) and outputs a composite serial stream of data on the TxD output pin on the falling edge of $\overline{TxC}$. The transmitter will begin transmission upon being enabled if $\overline{CTS}$ = 0. The TxD line will be held in the marking state immediately upon a master Reset or when Tx Enable or $\overline{CTS}$ is off or the transmitter is empty.

Transmitter Control

The Transmitter Control manages all activities associated with the transmission of serial data. It accepts and issues signals both externally and internally to accomplish this function.

TxRDY (Transmitter Ready)

This output signals the CPU that the transmitter is ready to accept a data character. The TxRDY output pin can be used as an interrupt to the system, since it is masked by TxEnable; or, for Polled operation, the CPU can check TxRDY using a Status Read operation. TxRDY is automatically reset by the leading edge of $\overline{WR}$ when a data character is loaded from the CPU.

Note that when using the Polled operation, the TxRDY status bit is *not* masked by TxEnable, but will only indicate the Empty/Full Status of the Tx Data Input Register.

TxE (Transmitter Empty)

When the 8251A has no characters to send, the TxEMPTY output will go "high." It resets upon receiving a character from CPU if the transmitter is enabled. TxEMPTY remains high when the transmitter is disabled. TxEMPTY can be used to indicate the end of a transmission mode, so that the CPU "knows" when to "turn the line around" in the half-duplex operational mode.

In the Synchronous mode, a "high" on this output indicates that a character has not been loaded and the SYNC character or characters are about to be or are being transmitted automatically as "fillers." TxEMPTY does not go low when the SYNC characters are being shifted out.

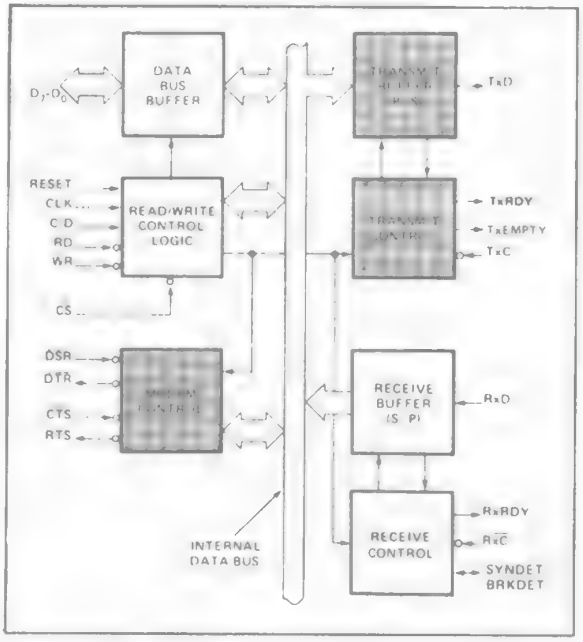


Figure 4. 8251A Block Diagram Showing Modem and Transmitter Buffer and Control Functions

$\overline{TxC}$ (Transmitter Clock)

The Transmitter Clock controls the rate at which the character is to be transmitted. In the Synchronous transmission mode, the Baud Rate (1x) is equal to the $\overline{TxC}$ frequency. In Asynchronous transmission mode, the baud rate is a fraction of the actual $\overline{TxC}$ frequency. A portion of the mode instruction selects this factor; it can be 1, 1/16 or 1/64 the $\overline{TxC}$.

For Example:

If Baud Rate equals 110 Baud,
$\overline{TxC}$ equals 110 Hz in the 1x mode.
$\overline{TxC}$ equals 1.72 kHz in the 16x mode.
$\overline{TxC}$ equals 7.04 kHz in the 64x mode.

The falling edge of $\overline{TxC}$ shifts the serial data out of the 8251A.

Receiver Buffer

The Receiver accepts serial data, converts this serial input to parallel format, checks for bits or characters that are unique to the communication technique and sends an "assembled" character to the CPU. Serial data is input to RxD pin, and is clocked in on the rising edge of $\overline{RxC}$.

Receiver Control

This functional block manages all receiver-related activities which consists of the following features.

The RxD initialization circuit prevents the 8251A from mistaking an unused input line for an active low data line in the "break condition." Before starting to receive serial characters on the RxD line, a valid "1" must first be detected after a chip master Reset. Once this has been determined, a search for a valid low (Start bit) is enabled. This feature is only active in the asynchronous mode, and is only done once for each master Reset.

The False Start bit detection circuit prevents false starts due to a transient noise spike by first detecting the falling edge and then strobing the nominal center of the Start bit (RxD = low).

Parity error detection sets the corresponding status bit.

The Framing Error status bit is set if the Stop bit is absent at the end of the data byte (asynchronous mode).

RxRDY (Receiver Ready)

This output indicates that the 8251A contains a character that is ready to be input to the CPU. RxRDY can be connected to the interrupt structure of the CPU or, for polled operation, the CPU can check the condition of RxRDY using a Status Read operation.

RxEnable, when off, holds RxRDY in the Reset Condition. For Asynchronous mode, to set RxRDY, the Receiver must be enabled to sense a Start Bit and a complete character must be assembled and transferred to the Data Output Register. For Synchronous mode, to set RxRDY, the Receiver must be enabled and a character must finish assembly and be transferred to the Data Output Register.

Failure to read the received character from the Rx Data Output Register prior to the assembly of the next Rx Data character will set overrun condition error and the previous character will be written over and lost. If the Rx Data is being read by the CPU when the internal transfer is occurring, overrun error will be set and the old character will be lost.

$\overline{RxC}$ (Receiver Clock)

The Receiver Clock controls the rate at which the character is to be received. In Synchronous Mode, the Baud Rate (1x) is equal to the actual frequency of $\overline{RxC}$. In Asynchronous Mode, the Baud Rate is a fraction of the actual $\overline{RxC}$ frequency. A portion of the mode instruction selects this factor: 1, 1/16 or 1/64 the $\overline{RxC}$.

For example:

Baud Rate equals 300 Baud, if
$\overline{RxC}$ equals 300 Hz in the 1x mode;
$\overline{RxC}$ equals 4800 Hz in the 16x mode;
$\overline{RxC}$ equals 19.2 kHz in the 64x mode.

Baud Rate equals 2400 Baud, if
$\overline{RxC}$ equals 2400 Hz in the 1x mode;
$\overline{RxC}$ equals 38.4 kHz in the 16x mode;
$\overline{RxC}$ equals 153.6 kHz in the 64x mode.

Data is sampled into the 8251A on the rising edge of $\overline{RxC}$.

NOTE: In most communications systems, the 8251A will be handling both the transmission and reception operations of a single link. Consequently, the Receive and Transmit Baud Rates will be the same. Both $\overline{TxC}$ and $\overline{RxC}$ will require identical frequencies for this operation and can be tied together and connected to a single frequency source (Baud Rate Generator) to simplify the interface.

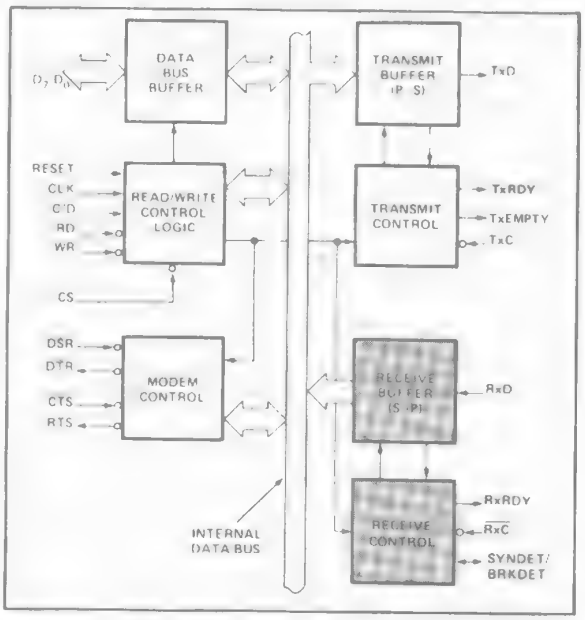


Figure 5. 8251A Block Diagram Showing Receiver Buffer and Control Functions

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SYNDET (SYNC Detect/ BRKDET Break Detect)

This pin is used in Synchronous Mode for SYNDET and may be used as either input or output, programmable through the Control Word. It is reset to output mode low upon RESET. When used as an output (internal Sync mode), the SYNDET pin will go "high" to indicate that the 8251A has located the SYNC character in the Receive mode. If the 8251A is programmed to use double Sync characters (bisync), then SYNDET will go "high" in the middle of the last bit of the second Sync character. SYNDET is automatically reset upon a Status Read operation.

When used as an input (external SYNC detect mode), a positive going signal will cause the 8251A to start assembling data characters on the rising edge of the next $\overline{RxC}$. Once in SYNC, the "high" input signal can be removed. When External SYNC Detect is programmed, Internal SYNC Detect is disabled.

BREAK (Async Mode Only)

This output will go high whenever the receiver remains low through two consecutive stop bit sequences (including the start bits, data bits, and parity bits). Break Detect may also be read as a Status bit. It is reset only upon a master chip Reset or Rx Data returning to a "one" state.

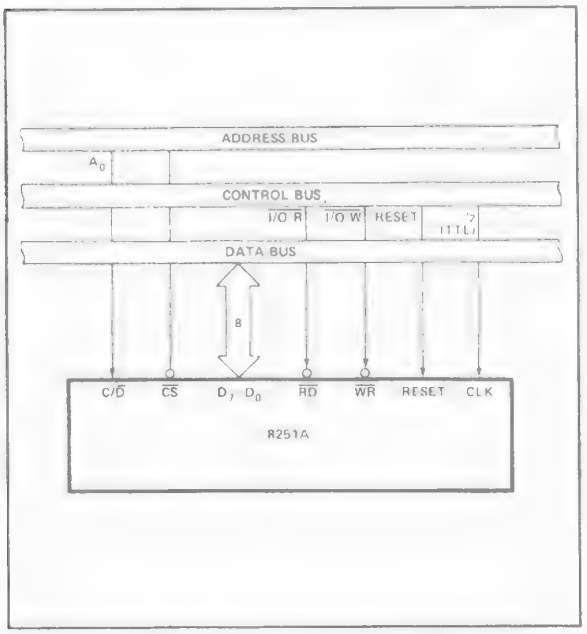

Figure 6. 8251A Interface to 8080 Standard System Bus

DETAILED OPERATION DESCRIPTION

General

The complete functional definition of the 8251A is programmed by the system's software. A set of control words must be sent out by the CPU to initialize the 8251A to support the desired communications format. These control words will program the: BAUD RATE, CHARACTER LENGTH, NUMBER OF STOP BITS, SYNCHRONOUS or ASYNCHRONOUS OPERATION, EVEN/ODD/OFF PARITY, etc. In the Synchronous Mode, options are also provided to select either internal or external character synchronization.

Once programmed, the 8251A is ready to perform its communication functions. The TxRDY output is raised "high" to signal the CPU that the 8251A is ready to receive a data character from the CPU. This output (TxRDY) is reset automatically when the CPU writes a character into the 8251A. On the other hand, the 8251A receives serial data from the MODEM or I/O device. Upon receiving an entire character, the RxRDY output is raised "high" to signal the CPU that the 8251A has a complete character ready for the CPU to fetch. RxRDY is reset automatically upon the CPU data read operation.

The 8251A cannot begin transmission until the Tx Enable (Transmitter Enable) bit is set in the Command Instruction and it has received a Clear To Send ($\overline{CTS}$) input. The TxD output will be held in the marking state upon Reset.

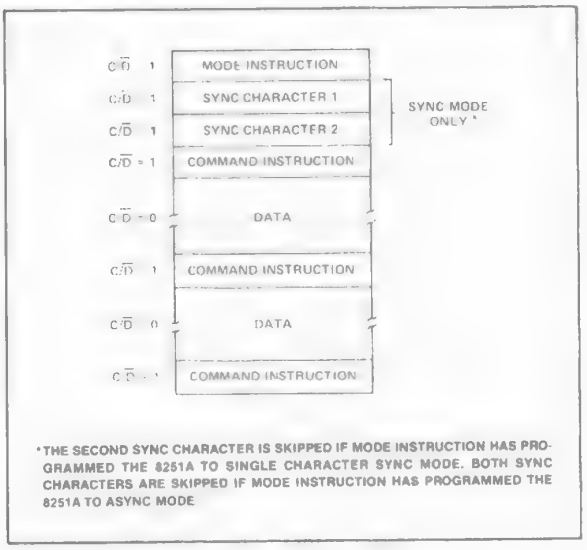

Figure 7. Typical Data Block

Programming the 8251A

Prior to starting data transmission or reception, the 8251A must be loaded with a set of control words generated by the CPU. These control signals define the complete functional definition of the 8251A and must immediately follow a Reset operation (internal or external).

The control words are split into two formats:

1. Mode Instruction
2. Command Instruction

Mode Instruction

This instruction defines the general operational characteristics of the 8251A. It must follow a Reset operation (internal or external). Once the Mode Instruction has been written into the 8251A by the CPU, SYNC characters or Command Instructions may be written.

Command Instruction

This instruction defines a word that is used to control the actual operation of the 8251A.

Both the Mode and Command Instructions must conform to a specified sequence for proper device operation (see Figure 7). The Mode Instruction must be written immediately following a Reset operation, prior to using the 8251A for data communication.

All control words written into the 8251A after the Mode Instruction will load the Command Instruction. Command Instructions can be written into the 8251A at any time in the data block during the operation of the 8251A. To return to the Mode Instruction format, the master Reset bit in the Command Instruction word can be set to initiate an internal Reset operation which automatically places the 8251A back into the Mode Instruction format. Command Instructions must follow the Mode Instructions or Sync characters.

Mode Instruction Definition

The 8251A can be used for either Asynchronous or Synchronous data communication. To understand how the Mode Instruction defines the functional operation of the 8251A, the designer can best view the device as two separate components, one Asynchronous and the other Synchronous, sharing the same package. The format definition can be changed only after a master chip Reset. For explanation purposes the two formats will be isolated.

NOTE: When parity is enabled it is not considered as one of the data bits for the purpose of programming the word length. The actual parity bit received on the Rx Data line cannot be read on the Data Bus. In the case of a programmed character length of less than 8 bits, the least significant Data Bus bits will hold the data; unused bits are "don't care" when writing data to the 8251A, and will be "zeros" when reading the data from the 8251A.

Asynchronous Mode (Transmission)

Whenever a data character is sent by the CPU the 8251A automatically adds a Start bit (low level) followed by the data bits (least significant bit first), and the programmed number of Stop bits to each character. Also, an even or odd Parity bit is inserted prior to the Stop bit(s), as defined by the Mode Instruction. The character is then transmitted as a serial data stream on the TxD output. The serial data is shifted out on the falling edge of $\overline{TxC}$ at a rate equal to 1, 1/16, or 1/64 that of the $\overline{TxC}$, as defined by the Mode Instruction. BREAK characters can be continuously sent to the TxD if commanded to do so.

When no data characters have been loaded into the 8251A the TxD output reamins "high" (marking) unless a Break (continuously low) has been programmed.

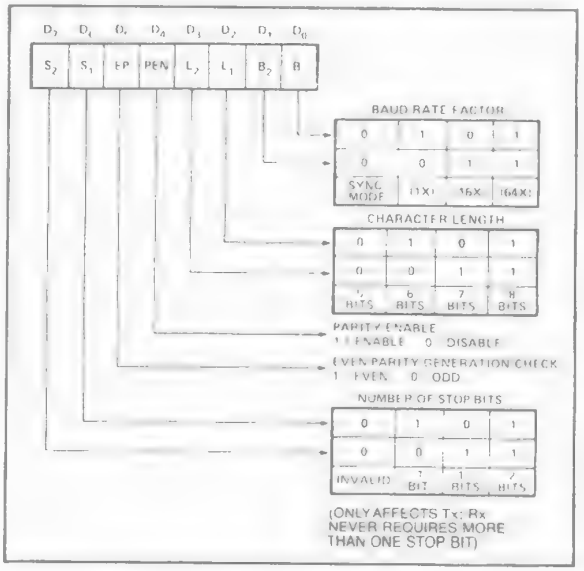

Figure 8. Mode Instruction Format, Asynchronous Mode

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Asynchronous Mode (Receive)

The RxD line is normally high. A falling edge on this line triggers the beginning of a START bit. The validity of this START bit is checked by again strobing this bit at its nominal center (16X or 64X mode only). If a low is detected again, it is a valid START bit, and the bit counter will start counting. The bit counter thus locates the center of the data bits, the parity bit (if it exists) and the stop bits. If parity error occurs, the parity error flag is set. Data and parity bits are sampled on the RxD pin with the rising edge of $\overline{RxC}$. If a low level is detected as the STOP bit, the Framing Error flag will be set. The STOP bit signals the end of a character. Note that the *receiver* requires only *one* stop bit, regardless of the number of stop bits programmed. This character is then loaded into the parallel I/O buffer of the 8251A. The RxRDY pin is raised to signal the CPU that a character is ready to be fetched. If a previous character has not been fetched by the CPU, the present character replaces it in the I/O buffer, and the OVERRUN Error flag is raised (thus the previous character is lost). All of the error flags can be reset by an Error Reset Instruction. The occurrence of any of these errors will not affect the operation of the 8251A.

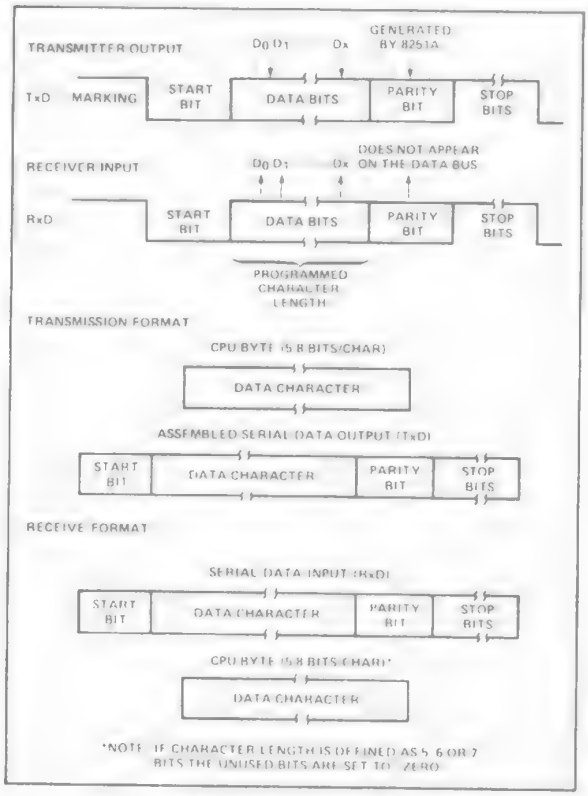
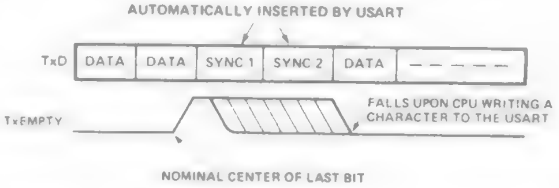


Figure 9. Asynchronous Mode

Synchronous Mode (Transmission)

The TxD output is continuously high until the CPU sends its first character to the 8251A which usually is a SYNC character. When the $\overline{CTS}$ line goes low, the first character is serially transmitted out. All characters are shifted out on the falling edge of $\overline{TxC}$. Data is shifted out at the same rate as the $\overline{TxC}$.

Once transmission has started, the data stream at the TxD output must continue at the $\overline{TxC}$ rate. If the CPU does not provide the 8251A with a data character before the 8251A Transmitter Buffers become empty, the SYNC characters (or character if in single SYNC character mode) will be automatically inserted in the TxD data stream. In this case, the TxEMPTY pin is raised high to signal that the 8251A is empty and SYNC characters are being sent out. TxEMPTY does not go low when the SYNC is being shifted out (see figure below). The TxEMPTY pin is internally reset by a data character being written into the 8251A.



Synchronous Mode (Receive)

In this mode, character synchronization can be internally or externally achieved. If the SYNC mode has been programmed, ENTER HUNT command should be included in the first command instruction word written. Data on the RxD pin is then sampled on the rising edge of $\overline{RxC}$. The content of the Rx buffer is compared at every bit boundary with the first SYNC character until a match occurs. If the 8251A has been programmed for two SYNC characters, the subsequent received character is also compared; when both SYNC characters have been detected, the USART ends the HUNT mode and is in character synchronization. The SYNDET pin is then set high, and is reset automatically by a STATUS READ. If parity is programmed, SYNDET will not be set until the middle of the parity bit instead of the middle of the last data bit.

In the external SYNC mode, synchronization is achieved by applying a high level on the SYNDET pin, thus forcing the 8251A out of the HUNT mode. The high level can be removed after one $\overline{RxC}$ cycle. An ENTER HUNT command has no effect in the asynchronous mode of operation.

Parity error and overrun error are both checked in the same way as in the Asynchronous Rx mode. Parity is checked when not in Hunt, regardless of whether the Receiver is enabled or not.

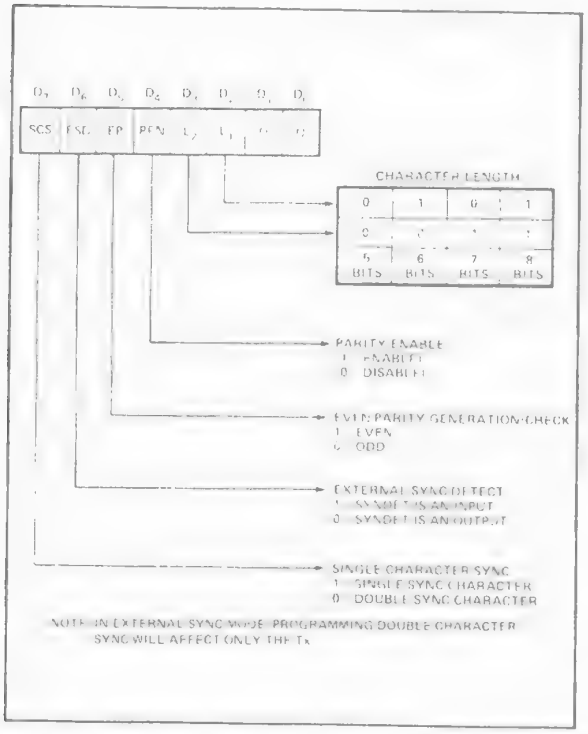


Figure 10. Mode Instruction Format, Synchronous Mode

The CPU can command the receiver to enter the HUNT mode if synchronization is lost. This will also set all the used character bits in the buffer to a "one," thus preventing a possible false SYNDET caused by data that happens to be in the Rx Buffer at ENTER HUNT time. Note that the SYNDET F/F is reset at each Status Read, regardless of whether internal or external SYNC has been programmed. This does not cause the 8251A to return to the HUNT mode. When in SYNC mode, but not in HUNT, Sync Detection is still functional, but only occurs at the "known" word boundaries. Thus, if one Status Read indicates SYNDET and a second Status Read also indicates SYNDET, then the programmed SYNDET characters have been received since the previous Status Read. (If double character sync has been programmed, then both sync characters have been contiguously received to gate a SYNDET indication.) When external SYNDET mode is selected, internal Sync Detect is disabled, and the SYNDET F/F may be set at any bit boundary.

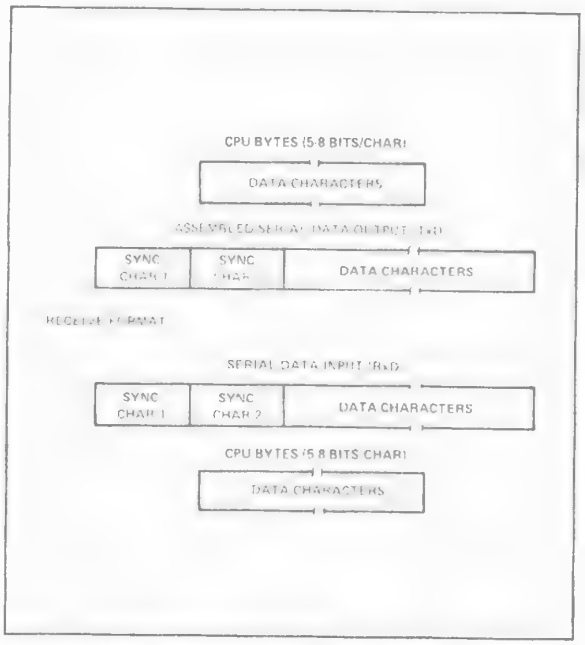


Figure 11. Data Format, Synchronous Mode

COMMAND INSTRUCTION DEFINITION

Once the functional definition of the 8251A has been programmed by the Mode Instruction and the sync characters are loaded (if in Sync Mode) then the device is ready to be used for data communication. The Command Instruction controls the actual operation of the selected format. Functions such as: Enable Transmit/Receive, Error Reset and Modem Controls are provided by the Command Instruction.

Once the Mode Instruction has been written into the 8251A and Sync characters inserted, if necessary, then all further "control writes" (C/D = 1) will load a Command Instruction. A Reset Operation (internal or external) will return the 8251A to the Mode Instruction format.

Note: Internal Reset on Power-up

When power is first applied, the 8251A may come up in the Mode, Sync character or Command format. To guarantee that the device is in the Command Instruction format before the Reset command is issued, it is safest to execute the worst-case initialization sequence (sync mode with two sync characters). Loading three 00Hs consecutively into the device with C/$\overline{D}$ = 1 configures sync operation and writes two dummy 00H sync characters. An Internal Reset command (40H) may then be issued to return the device to the "Idle" state.

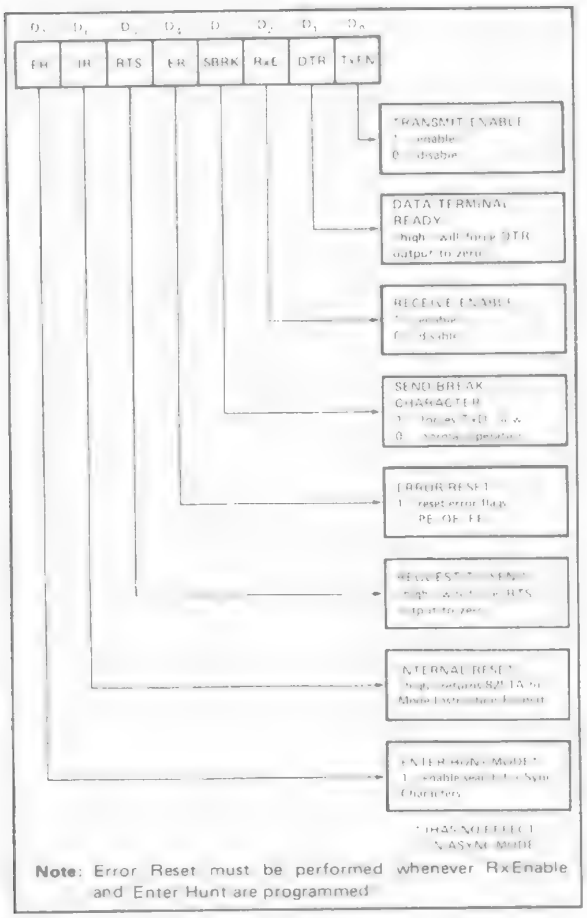


Figure 12. Command Instruction Format

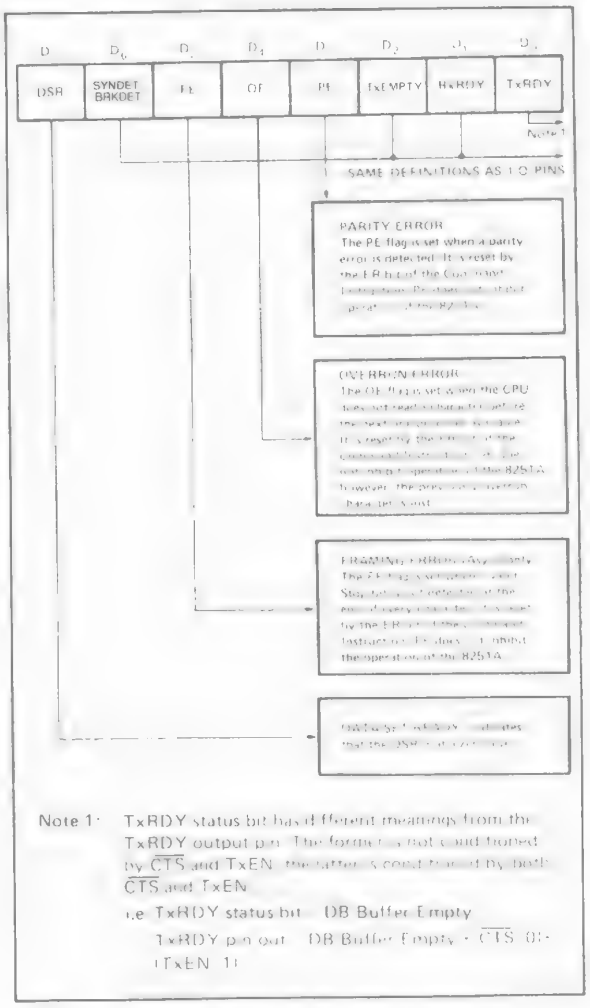


Figure 13. Status Read Format

STATUS READ DEFINITION

In data communication systems it is often necessary to examine the "status" of the active device to ascertain if errors have occurred or other conditions that require the processor's attention. The 8251A has facilities that allow the programmer to "read" the status of the device at any time during the functional operation. (Status update is inhibited during status read.)

A normal "read" command is issued by the CPU with $C/\overline{D} = 1$ to accomplish this function.

Some of the bits in the Status Read Format have identical meanings to external output pins so that the 8251A can be used in a completely polled or interrupt-driven environment. TxRDY is an exception.

Note that status update can have a maximum delay of 28 clock periods from the actual event affecting the status.

APPLICATIONS OF THE 8251A

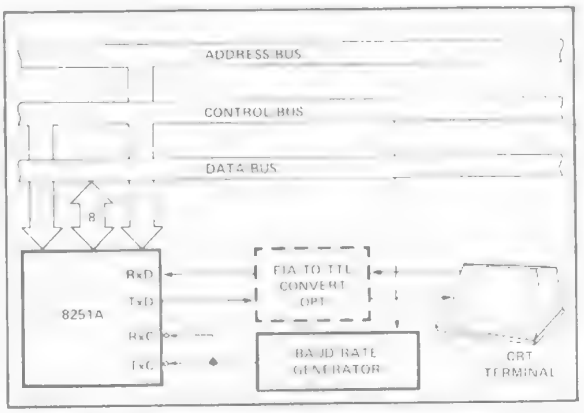


Figure 14. Asynchronous Serial Interface to CRT Terminal, DC—9600 Baud

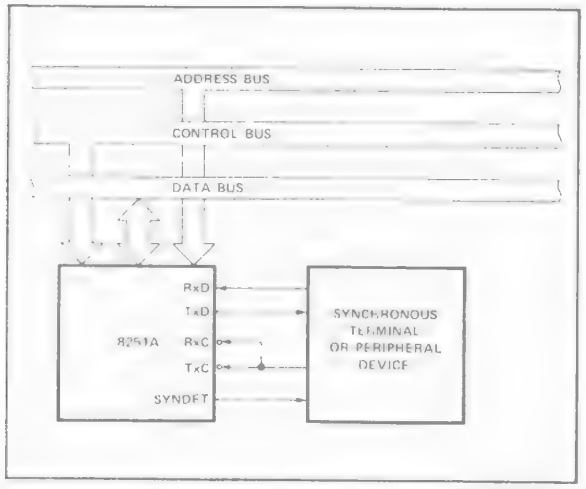


Figure 15. Synchronous Interface to Terminal or Peripheral Device

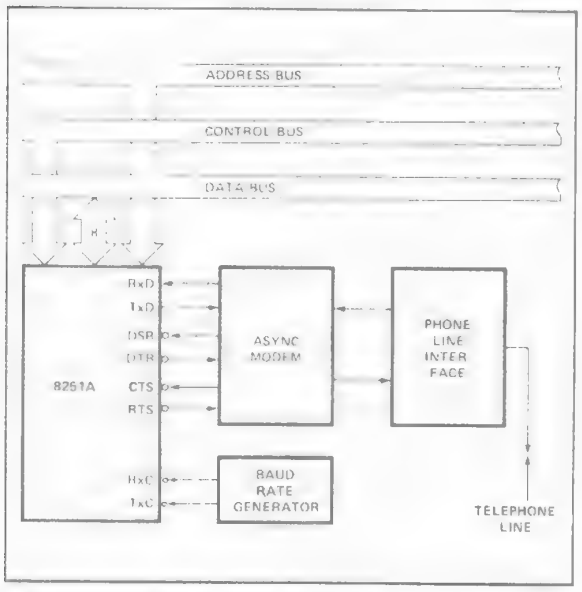


Figure 16. Asynchronous Interface to Telephone Lines

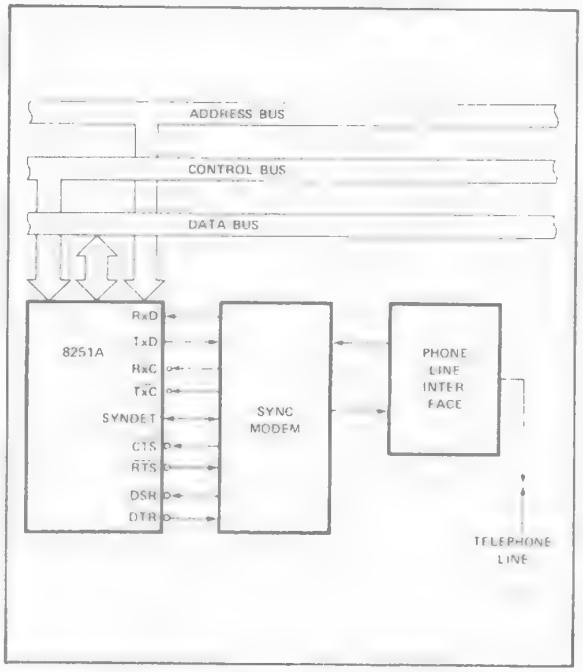


Figure 17. Synchronous Interface to Telephone Lines

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage On Any Pin
With Respect To Ground ..... −0.5V to +7V
Power Dissipation ..... 1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5.0V ±10%, GND = 0V)*

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_{IL}	Input Low Voltage	−0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC}	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2.2 mA
V_{OH}	Output High Voltage	2.4		V	I_{OL} = −400 μA
I_{OFL}	Output Float Leakage		−10	μA	V_{OUT} = V_{CC} TO 0.45V
I_{IL}	Input Leakage		±10	μA	V_{IN} = V_{CC} TO 0.45V
I_{CC}	Power Supply Current		100	mA	All Outputs = High

CAPACITANCE (T_A = 25°C, V_{CC} = GND = 0V)

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
C_{IN}	Input Capacitance		10	pF	fc = 1MHz
$C_{I/O}$	I/O Capacitance		20	pF	Unmeasured pins returned to GND

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5.0V ±10%, GND = 0V)*

Bus Parameters (Note 1)

READ CYCLE

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AR}	Address Stable Before $\overline{READ}$ ($\overline{CS}$, C/$\overline{D}$)	0		ns	Note 2
t_{RA}	Address Hold Time for $\overline{READ}$ ($\overline{CS}$, C/$\overline{D}$)	0		ns	Note 2
t_{RR}	$\overline{READ}$ Pulse Width	250		ns	
t_{RD}	Data Delay from $\overline{READ}$		200	ns	3, C_L = 150 pF
t_{DF}	$\overline{READ}$ to Data Floating	10	100	ns	

WRITE CYCLE

Symbol	Parameter	Min.	Max.	Unit	Test Condtions
t_{AW}	Address Stable Before $\overline{WRITE}$	0		ns	
t_{WA}	Address Hold Time for $\overline{WRITE}$	0		ns	
t_{WW}	$\overline{WRITE}$ Pulse Width	250		ns	
t_{DW}	Data Set-Up Time for $\overline{WRITE}$	150		ns	
t_{WD}	Data Hold Time for $\overline{WRITE}$	20		ns	
t_{RV}	Recovery Time Between WRITES	6		t_{CY}	Note 4

A.C. CHARACTERISTICS (Continued)

OTHER TIMINGS

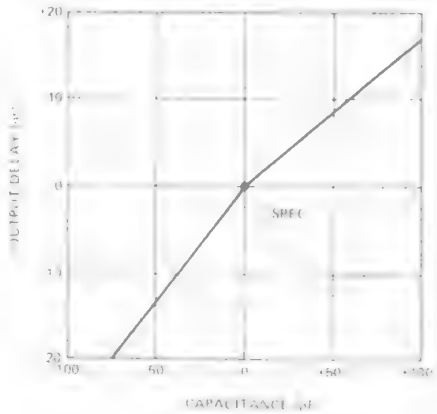
Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{CY}	Clock Period	320	1350	ns	Notes 5, 6
t_{ϕ}	Clock High Pulse Width	120	$t_{CY}-90$	ns	
$t_{\bar{\phi}}$	Clock Low Pulse Width	90		ns	
t_R, t_F	Clock Rise and Fall Time		20	ns	
t_{DTx}	TxD Delay from Falling Edge of $\overline{TxC}$		1	μs	
f_{Tx}	Transmitter Input Clock Frequency				
	1x Baud Rate	DC	64	kHz	
	16x Baud Rate	DC	310	kHz	
	64x Baud Rate	DC	615	kHz	
t_{TPW}	Transmitter Input Clock Pulse Width				
	1x Baud Rate	12		t_{CY}	
	16x and 64x Baud Rate	1		t_{CY}	
t_{TPD}	Transmitter Input Clock Pulse Delay				
	1x Baud Rate	15		t_{CY}	
	16x and 64x Baud Rate	3		t_{CY}	
f_{Rx}	Receiver Input Clock Frequency				
	1x Baud Rate	DC	64	kHz	
	16x Baud Rate	DC	310	kHz	
	64x Baud Rate	DC	615	kHz	
t_{RPW}	Receiver Input Clock Pulse Width				
	1x Baud Rate	12		t_{CY}	
	16x and 64x Baud Rate	1		t_{CY}	
t_{RPD}	Receiver Input Clock Pulse Delay				
	1x Baud Rate	15		t_{CY}	
	16x and 64x Baud Rate	3		t_{CY}	
t_{TxRDY}	TxRDY Pin Delay from Center of Last Bit		[redacted]	t_{CY}	Note 7
$t_{TxRDY\ CLEAR}$	TxRDY ↓ from Leading Edge of $\overline{WR}$		400	ns	Note 7
t_{RxRDY}	RxRDY Pin Delay from Center of Last Bit		26	t_{CY}	Note 7
$t_{RxRDY\ CLEAR}$	RxRDY ↓ from Leading Edge of $\overline{RD}$		400	ns	Note 7
t_{IS}	Internal SYNDET Delay from Rising Edge of $\overline{RxC}$		26	t_{CY}	Note 7
t_{ES}	External SYNDET Set-Up Time After Rising Edge of $\overline{RxC}$	18		t_{CY}	Note 7
$t_{TxEMPTY}$	TxEMPTY Delay from Center of Last Bit	20		t_{CY}	Note 7
t_{WC}	Control Delay from Rising Edge of WRITE (TxEn, $\overline{DTR}$, $\overline{RTS}$)	[redacted]		t_{CY}	Note 7
t_{CR}	Control to READ Set-Up Time ($\overline{DSR}$, $\overline{CTS}$)	20		t_{CY}	Note 7

*NOTE:
1. For Extended Temperature EXPRESS, use M8251A electrical parameters.

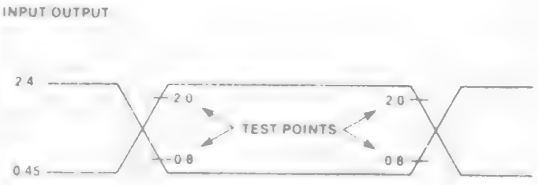
A.C. CHARACTERISTICS (Continued)

NOTES:
1. AC timings measured V_{OH} = 2.0 V_{OL} = 2.0, V_{OL} = 0.8, and with load circuit of Figure 1.
2. Chip Select (CS) and Command/Data (C/D) are considered as Addresses.
3. Assumes that Address is valid before $R_D\downarrow$.
4. This recovery time is for Mode Initialization only. Write Data is allowed only when TxRDY = 1. Recovery Time between Writes for Asynchronous Mode is 8 t_{CY} and for Synchronous Mode is 16 t_{CY}.
5. The TxC and RxC frequencies have the following limitations with respect to CLK: For 1x Baud Rate, f_{Tx} or $f_{Rx} \leq 1$ (30 t_{CY}):
   For 16x and 64x Baud Rate, f_{Tx} or $f_{Rx} \leq 1/(4.5\ t_{CY})$.
6. Reset Pulse Width = 6 t_{CY} minimum; System Clock must be running during Reset.
7. Status update can have a maximum delay of 28 clock periods from the event affecting the status.

TYPICAL Δ OUTPUT DELAY VS. Δ CAPACITANCE (pF)

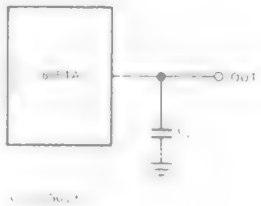


A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING: INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0". TIMING MEASUREMENTS ARE MADE AT 2.0V FOR A LOGIC "1" AND 0.8V FOR A LOGIC "0".

A.C. TESTING LOAD CIRCUIT



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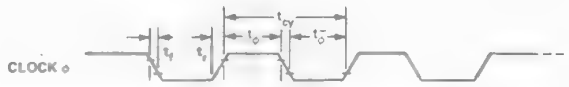
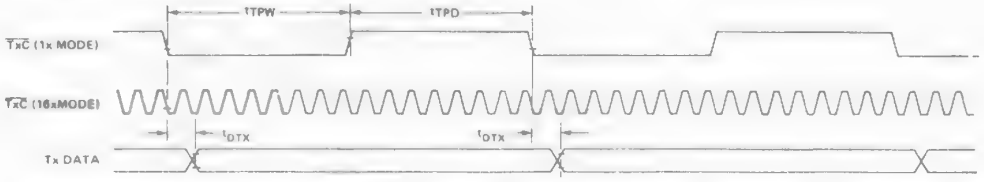
WAVEFORMS

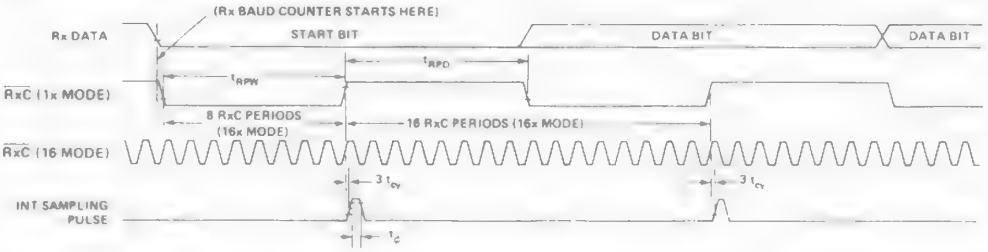
SYSTEM CLOCK INPUT



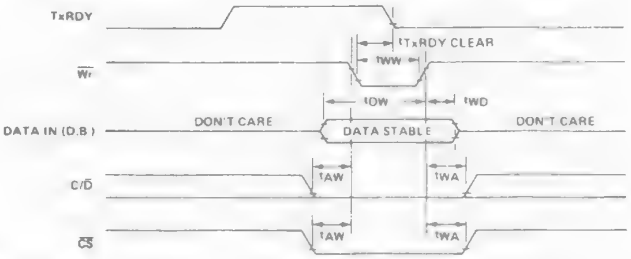
TRANSMITTER CLOCK AND DATA



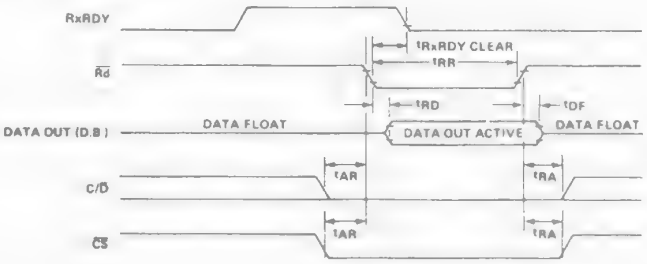
RECEIVER CLOCK AND DATA



WRITE DATA CYCLE (CPU → USART)



READ DATA CYCLE (CPU ← USART)



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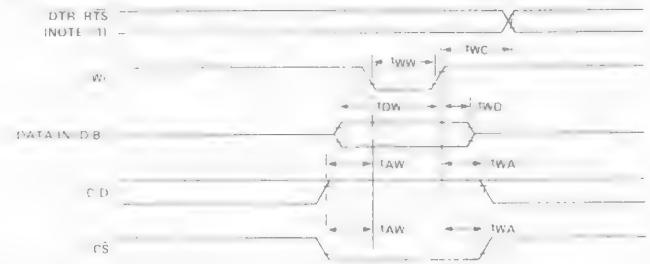
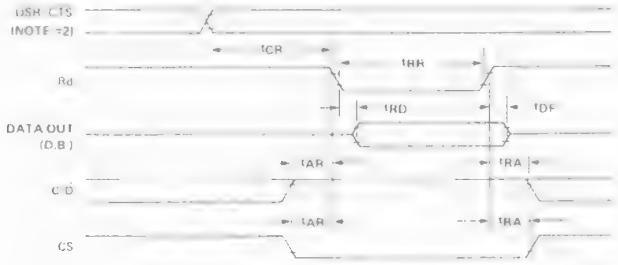
WAVEFORMS (Continued)

WRITE CONTROL OR OUTPUT PORT CYCLE (CPU → USART)

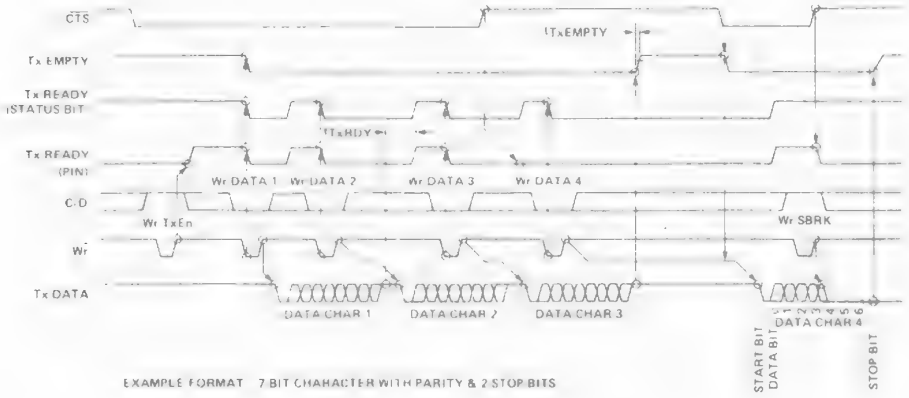


READ CONTROL OR INPUT PORT (CPU ← USART)



NOTE #1: T_{WC} INCLUDES THE RESPONSE TIMING OF A CONTROL BYTE.
NOTE #2: T_{CR} INCLUDES THE EFFECT OF CTS ON THE TxENBL CIRCUITRY

TRANSMITTER CONTROL AND FLAG TIMING (ASYNC MODE)



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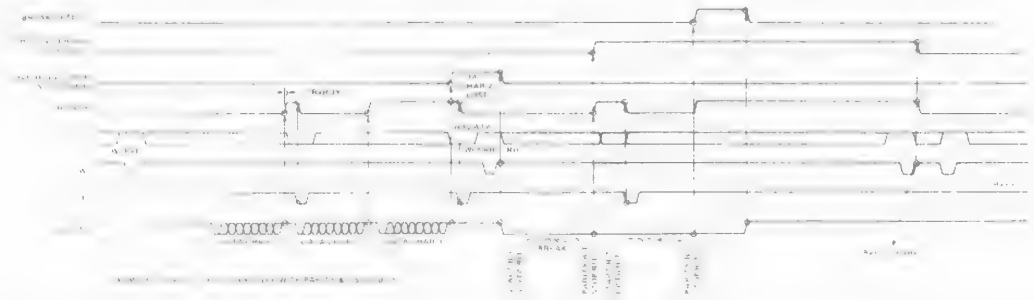
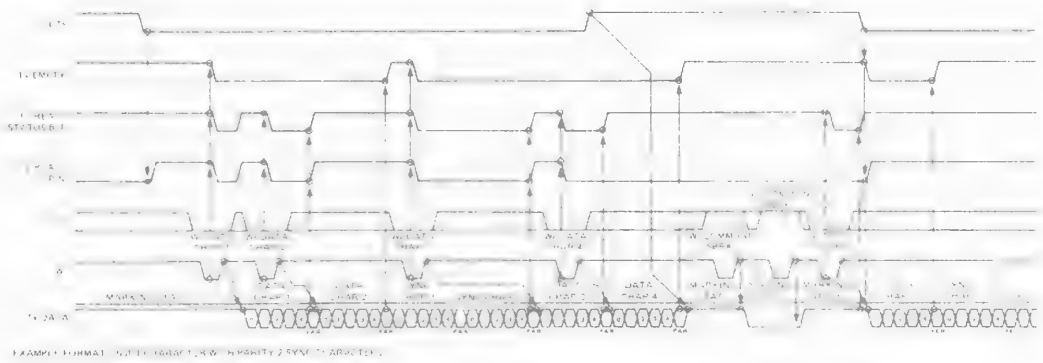
WAVEFORMS (Continued)

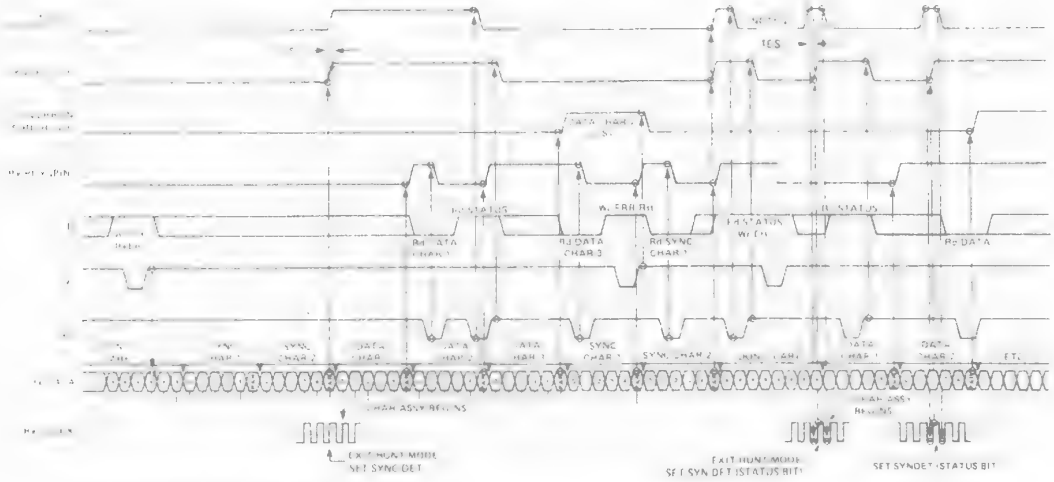
RECEIVER CONTROL AND FLAG TIMING (ASYNC MODE)



TRANSMITTER CONTROL AND FLAG TIMING (SYNC MODE)



RECEIVER CONTROL AND FLAG TIMING (SYNC MODE)



8253/8253-5
PROGRAMMABLE INTERVAL TIMER

- **MCS-85™ Compatible 8253-5**
- **3 Independent 16-Bit Counters**
- **DC to 2 MHz**
- **Programmable Counter Modes**
- **Count Binary or BCD**
- **Single +5V Supply**
- **Available in EXPRESS**
  —Standard Temperature Range
  —Extended Temperature Range

The Intel® 8253 is a programmable counter/timer chip designed for use as an Intel microcomputer peripheral. It uses nMOS technology with a single +5V supply and is packaged in a 24-pin plastic DIP.

It is organized as 3 independent 16-bit counters, each with a count rate of up to 2 MHz. All modes of operation are software programmable.

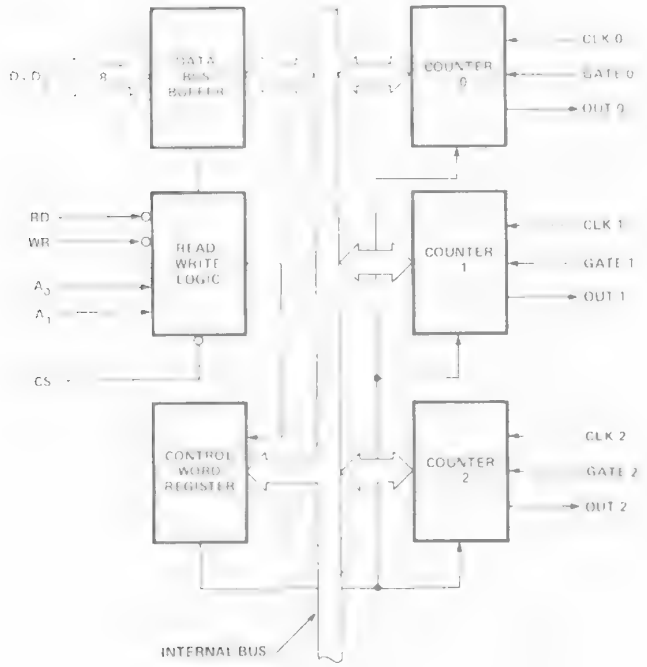


Figure 1. Block Diagram

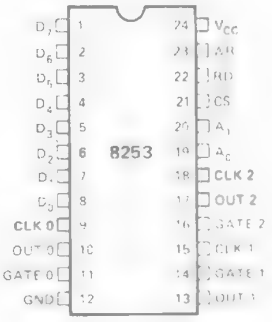


Figure 2. Pin Configuration

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AFN 00745C

FUNCTIONAL DESCRIPTION

General

The 8253 is a programmable interval timer/counter specifically designed for use with the Intel™ Microcomputer systems. Its function is that of a general purpose, multi-timing element that can be treated as an array of I/O ports in the system software.

The 8253 solves one of the most common problems in any microcomputer system, the generation of accurate time delays under software control. Instead of setting up timing loops in systems software, the programmer configures the 8253 to match his requirements, initializes one of the counters of the 8253 with the desired quantity, then upon command the 8253 will count out the delay and interrupt the CPU when it has completed its tasks. It is easy to see that the software overhead is minimal and that multiple delays can easily be maintained by assignment of priority levels.

Other counter/timer functions that are non-delay in nature but also common to most microcomputers can be implemented with the 8253.

- Programmable Rate Generator
- Event Counter
- Binary Rate Multiplier
- Real Time Clock
- Digital One-Shot
- Complex Motor Controller

Data Bus Buffer

This 3-state, bi-directional, 8-bit buffer is used to interface the 8253 to the system data bus. Data is transmitted or received by the buffer upon execution of INput or OUTput CPU instructions. The Data Bus Buffer has three basic functions.

1. Programming the MODES of the 8253.
2. Loading the count registers.
3. Reading the count values.

Read/Write Logic

The Read/Write Logic accepts inputs from the system bus and in turn generates control signals for overall device operation. It is enabled or disabled by CS so that no operation can occur to change the function unless the device has been selected by the system logic.

$\overline{RD}$ (Read)

A "low" on this input informs the 8253 that the CPU is inputting data in the form of a counters value.

$\overline{WR}$ (Write)

A "low" on this input informs the 8253 that the CPU is outputting data in the form of mode information or loading counters.

A0, A1

These inputs are normally connected to the address bus. Their function is to select one of the three counters to be operated on and to address the control word register for mode selection.

$\overline{CS}$ (Chip Select)

A "low" on this input enables the 8253. No reading or writing will occur unless the device is selected. The $\overline{CS}$ input has no effect upon the actual operation of the counters.

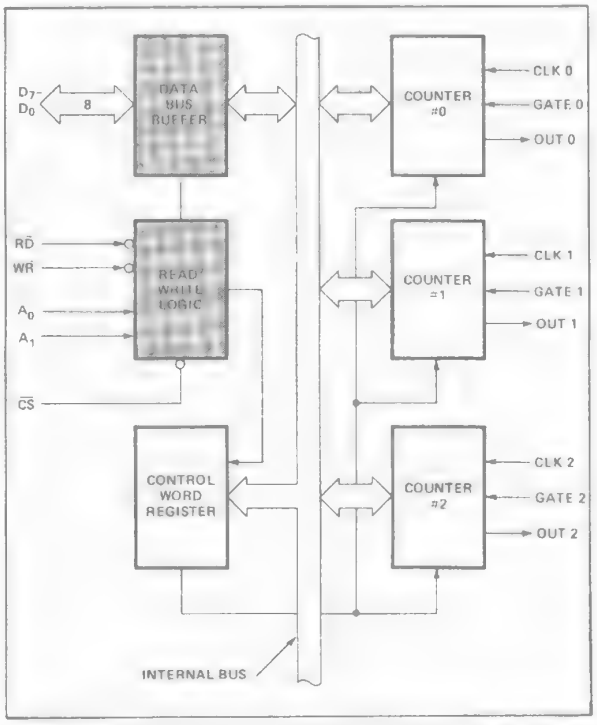


Figure 3. Block Diagram Showing Data Bus Buffer and Read/Write Logic Functions

$\overline{CS}$	$\overline{RD}$	$\overline{WR}$	A_1	A_0	
0	1	0	0	0	Load Counter No. 0
0	1	0	0	1	Load Counter No. 1
0	1	0	1	0	Load Counter No. 2
0	1	0	1	1	Write Mode Word
0	0	1	0	0	Read Counter No. 0
0	0	1	0	1	Read Counter No. 1
0	0	1	1	0	Read Counter No. 2
0	0	1	1	1	No-Operation 3-State
1	X	X	X	X	Disable 3-State
0	1	1	X	X	No-Operation 3-State

Control Word Register

The Control Word Register is selected when A0, A1 are 11. It then accepts information from the data bus buffer and stores it in a register. The information stored in this register controls the operational MODE of each counter, selection of binary or BCD counting and the loading of each count register.

The Control Word Register can only be written into; no read operation of its contents is available.

Counter #0, Counter #1, Counter #2

These three functional blocks are identical in operation so only a single Counter will be described. Each Counter consists of a single, 16-bit, pre-settable, DOWN counter. The counter can operate in either binary or BCD and its input, gate and output are configured by the selection of MODES stored in the Control Word Register.

The counters are fully independent and each can have separate Mode configuration and counting operation, binary or BCD. Also, there are special features in the control word that handle the loading of the count value so that software overhead can be minimized for these functions.

The reading of the contents of each counter is available to the programmer with simple READ operations for event counting applications and special commands and logic are included in the 8253 so that the contents of each counter can be read "on the fly" without having to inhibit the clock input.

8253 SYSTEM INTERFACE

The 8253 is a component of the Intel™ Microcomputer Systems and interfaces in the same manner as all other peripherals of the family. It is treated by the systems software as an array of peripheral I/O ports; three are counters and the fourth is a control register for MODE programming.

Basically, the select inputs A0, A1 connect to the A0, A1 address bus signals of the CPU. The $\overline{CS}$ can be derived directly from the address bus using a linear select method. Or it can be connected to the output of a decoder, such as an Intel® 8205 for larger systems

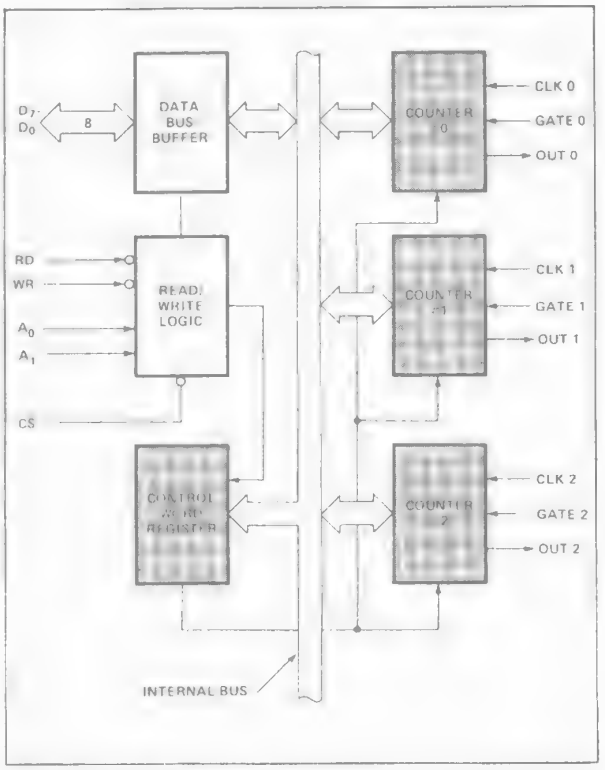


Figure 4. Block Diagram Showing Control Word Register and Counter Functions

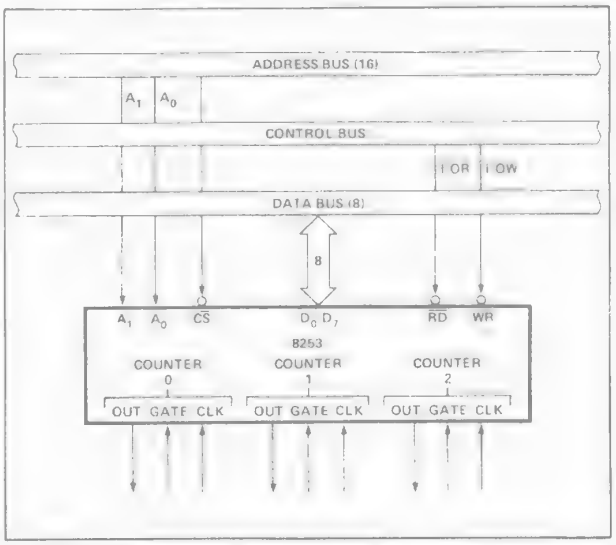


Figure 5. 8253 System Interface

OPERATIONAL DESCRIPTION

General

The complete functional definition of the 8253 is programmed by the systems software. A set of control words must be sent out by the CPU to initialize each counter of the 8253 with the desired MODE and quantity information. Prior to initialization, the MODE, count, and output of all counters is undefined. These control words program the MODE, Loading sequence and selection of binary or BCD counting.

Once programmed, the 8253 is ready to perform whatever timing tasks it is assigned to accomplish.

The actual counting operation of each counter is completely independent and additional logic is provided on-chip so that the usual problems associated with efficient monitoring and management of external, asynchronous events or rates to the microcomputer system have been eliminated.

Programming the 8253

All of the MODES for each counter are programmed by the systems software by simple I/O operations

Each counter of the 8253 is individually programmed by writing a control word into the Control Word Register. (A0, A1 = 11)

Control Word Format

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
SC1	SC0	RL1	RL0	M2	M1	M0	BCD

Definition of Control

SC — Select Counter:

SC1	SC0	
0	0	Select Counter 0
0	1	Select Counter 1
1	0	Select Counter 2
1	1	Illegal

RL — Read/Load:

RL1	RL0	
0	0	Counter Latching operation (see READ/WRITE Procedure Section)
1	0	Read/Load most significant byte only.
0	1	Read/Load least significant byte only.
1	1	Read/Load least significant byte first, then most significant byte.

M — MODE:

M2	M1	M0	
0	0	0	Mode 0
0	0	1	Mode 1
X	1	0	Mode 2
X	1	1	Mode 3
1	0	0	Mode 4
1	0	1	Mode 5

BCD:

0	Binary Counter 16-bits
1	Binary Coded Decimal (BCD) Counter (4 Decades)

Counter Loading

The count register is not loaded until the count value is written (one or two bytes, depending on the mode selected by the RL bits), followed by a rising edge and a falling edge of the clock. Any read of the counter prior to that falling clock edge may yield invalid data.

MODE Definition

MODE 0: Interrupt on Terminal Count. The output will be initially low after the mode set operation. After the count is loaded into the selected count register, the output will remain low and the counter will count. When terminal count is reached the output will go high and remain high until the selected count register is reloaded with the mode or a new count is loaded. The counter continues to decrement after terminal count has been reached.

Rewriting a counter register during counting results in the following:

(1) Write 1st byte stops the current counting.
(2) Write 2nd byte starts the new count.

MODE 1: Programmable One-Shot. The output will go low on the count following the rising edge of the gate input.

The output will go high on the terminal count. If a new count value is loaded while the output is low it will not affect the duration of the one-shot pulse until the succeeding trigger. The current count can be read at any time without affecting the one-shot pulse.

The one-shot is retriggerable, hence the output will remain low for the full count after any rising edge of the gate input.

MODE 2: Rate Generator. Divide by N counter. The output will be low for one period of the input clock. The period from one output pulse to the next equals the number of input counts in the count register. If the count register is reloaded between output pulses the present period will not be affected, but the subsequent period will reflect the new value.

The gate input, when low, will force the output high. When the gate input goes high, the counter will start from the initial count. Thus, the gate input can be used to synchronize the counter.

When this mode is set, the output will remain high until after the count register is loaded. The output then can also be synchronized by software.

MODE 3: Square Wave Rate Generator. Similar to MODE 2 except that the output will remain high until one half the count has been completed (for even numbers) and go low for the other half of the count. This is accomplished by decrementing the counter by two on the falling edge of each clock pulse. When the counter reaches terminal count, the state of the output is changed and the counter is reloaded with the full count and the whole process is repeated.

If the count is odd and the output is high, the first clock pulse (after the count is loaded) decrements the count by 1. Subsequent clock pulses decrement the clock by 2. After timeout, the output goes low and the full count is reloaded. The first clock pulse (following the reload) decrements the counter by 3. Subsequent clock pulses decrement the count by 2 until timeout. Then the whole process is repeated. In this way, if the count is odd, the output will be high for (N + 1)/2 counts and low for (N – 1)/2 counts.

MODE 4: Software Triggered Strobe. After the mode is set, the output will be high. When the count is loaded, the counter will begin counting. On terminal count, the output will go low for one input clock period, then will go high again.

If the count register is reloaded during counting, the new count will be loaded on the next CLK pulse. The count will be inhibited while the GATE input is low.

MODE 5: Hardware Triggered Strobe. The counter will start counting after the rising edge of the trigger input and will go low for one clock period when the terminal count is reached. The counter is retriggerable. The output will not go low until the full count after the rising edge of any trigger.

Modes \ Signal Status	Low Or Going Low	Rising	High
0	Disables counting	—	Enables counting
1	— —	1) Initiates counting 2) Resets output after next clock	— —
2	1) Disables counting 2) Sets output immediately high	1) Reloads counter 2) Initiates counting	Enables counting
3	1) Disables counting 2) Sets output immediately high	Initiates counting	Enables counting
4	Disables counting	— —	Enables counting
5	— —	Initiates counting	— —

Figure 6. Gate Pin Operations Summary

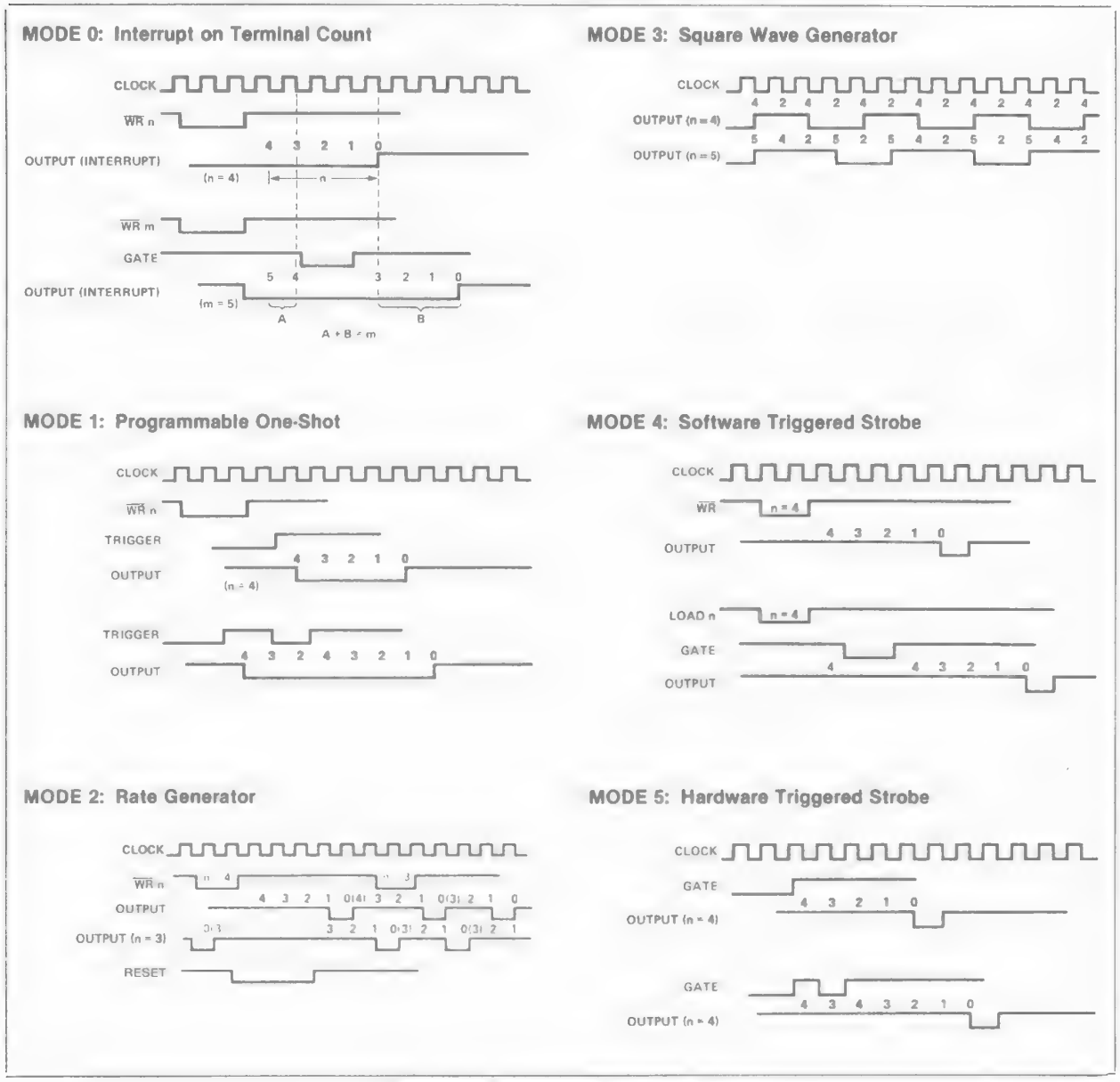


Figure 7. 8253 Timing Diagrams

8253 READ/WRITE PROCEDURE

Write Operations

The systems software must program each counter of the 8253 with the mode and quantity desired. The programmer must write out to the 8253 a MODE control word and the programmed number of count register bytes (1 or 2) prior to actually using the selected counter.

The actual order of the programming is quite flexible. Writing out of the MODE control word can be in any sequence of counter selection, e.g., counter #0 does not have to be first or counter #2 last. Each counter's MODE control word register has a separate address so that its loading is completely sequence independent. (SC0, SC1)

The loading of the Count Register with the actual count value, however, must be done in exactly the sequence programmed in the MODE control word (RL0, RL1). This loading of the counter's count register is still sequence independent like the MODE control word loading, but when a selected count register is to be loaded it must be loaded with the number of bytes programmed in the MODE control word (RL0, RL1). The one or two bytes to be loaded in the count register do not have to follow the associated MODE control word. They can be programmed at any time following the MODE control word loading as long as the correct number of bytes is loaded in order.

All counters are down counters. Thus, the value loaded into the count register will actually be decremented. Loading all zeroes into a count register will result in the maximum count (2^{16} for Binary or 10^4 for BCD). In MODE 0 the new count will not restart until the load has been completed. It will accept one of two bytes depending on how the MODE control words (RL0, RL1) are programmed. Then proceed with the restart operation.

	MODE Control Word Counter n
LSB	Count Register byte Counter n
MSB	Count Register byte Counter n

Note: Format shown is a simple example of loading the 8253 and does not imply that it is the only format that can be used.

Figure 8. Programming Format

			A1	A0
No. 1		MODE Control Word Counter 0	1	1
No. 2		MODE Control Word Counter 1	1	1
No. 3		MODE Control Word Counter 2	1	1
No. 4	LSB	Count Register Byte Counter 1	0	1
No. 5	MSB	Count Register Byte Counter 1	0	1
No. 6	LSB	Count Register Byte Counter 2	1	0
No. 7	MSB	Count Register Byte Counter 2	1	0
No. 8	LSB	Count Register Byte Counter 0	0	0
No. 9	MSB	Count Register Byte Counter 0	0	0

Note: The exclusive addresses of each counter's count register make the task of programming the 8253 a very simple matter, and maximum effective use of the device will result if this feature is fully utilized.

Figure 9. Alternate Programming Formats

Read Operations

In most counter applications it becomes necessary to read the value of the count in progress and make a computational decision based on this quantity. Event counters are probably the most common application that uses this function. The 8253 contains logic that will allow the programmer to easily read the contents of any of the three counters without disturbing the actual count in progress

There are two methods that the programmer can use to read the value of the counters. The first method involves the use of simple I/O read operations of the selected counter. By controlling the A0, A1 inputs to the 8253 the programmer can select the counter to be read (remember that no read operation of the mode register is allowed A0, A1-11). The only requirement with this method is that in order to assure a stable count reading the actual operation of the selected counter must be inhibited either by controlling the Gate input or by external logic that inhibits the clock input. The contents of the counter selected will be available as follows:

first I/O Read contains the least significant byte (LSB).

second I/O Read contains the most significant byte (MSB).

Due to the internal logic of the 8253 it is absolutely necessary to complete the entire reading procedure. If two bytes are programmed to be read then two bytes must be read before any loading WR command can be sent to the same counter.

Read Operation Chart

A1	A0	RD	
0	0	0	Read Counter No. 0
0	1	0	Read Counter No. 1
1	0	0	Read Counter No. 2
1	1	0	Illegal

Reading While Counting

In order for the programmer to read the contents of any counter without effecting or disturbing the counting operation the 8253 has special internal logic that can be accessed using simple WR commands to the MODE register. Basically, when the programmer wishes to read the contents of a selected counter "on the fly" he loads the MODE register with a special code which latches the present count value into a storage register so that its contents contain an accurate, stable quantity. The programmer then issues a normal read command to the selected counter and the contents of the latched register is available.

MODE Register for Latching Count

A0, A1 = 11

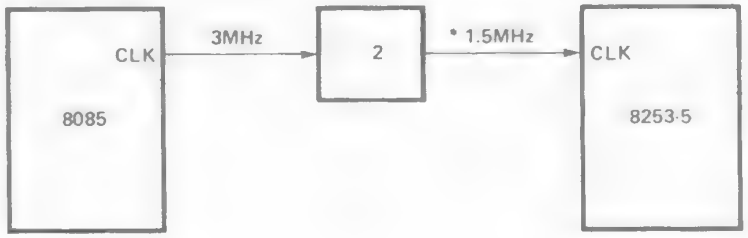
D7	D6	D5	D4	D3	D2	D1	D0
SC1	SC0	0	0	X	X	X	X

SC1,SC0 — specify counter to be latched.

D5,D4 — 00 designates counter latching operation.

X — don't care

The same limitation applies to this mode of reading the counter as the previous method. That is, it is mandatory to complete the entire read operation as programmed. This command has no effect on the counter's mode.



*If an 8085 clock output is to drive an 8253-5 clock input, it must be reduced to 2 MHz or less

Figure 10. MCS-85™ Clock Interface*

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage On Any Pin
With Respect to Ground ..... −0.5 V to +7 V
Power Dissipation ..... 1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ±10%) *

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_{IL}	Input Low Voltage	-0.5	0.8	V	
V_{IH}	Input High Voltage	2.2	V_{CC}+.5V	V	
V_{OL}	Output Low Voltage		0.45	V	Note 1
V_{OH}	Output High Voltage	2.4		V	Note 2
I_{IL}	Input Load Current		±10	μA	V_{IN} = V_{CC} to 0V
I_{OFL}	Output Float Leakage		±10	μA	V_{OUT} = V_{CC} to .45V
I_{CC}	V_{CC} Supply Current		140	mA	

CAPACITANCE (T_A = 25°C, V_{CC} = GND = 0V)

Symbol	Parameter	Min.	Typ.	Max.	Unit	Test Conditions
C_{IN}	Input Capacitance			10	pF	fc = 1 MHz
$C_{I/O}$	I/O Capacitance			20	pF	Unmeasured pins returned to V_{SS}

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5.0V ± 10%, GND = 0V) *

Bus Parameters (Note 3)

READ CYCLE

Symbol	Parameter	8253		8253-5		Unit
		Min.	Max.	Min.	Max.	
t_{AR}	Address Stable Before $\overline{READ}$	50		30		ns
t_{RA}	Address Hold Time for $\overline{READ}$	5		5		ns
t_{RR}	$\overline{READ}$ Pulse Width	400		300		ns
t_{RD}	Data Delay From $\overline{READ}$[4]		300		200	ns
t_{DF}	$\overline{READ}$ to Data Floating	25	125	25	100	ns
t_{RV}	Recovery Time Between READ and Any Other Control Signal	1		1		μs

AFN-00745C

A.C. CHARACTERISTICS (Continued)

WRITE CYCLE

Symbol	Parameter	8253		8253-5		Unit
		Min.	Max.	Min.	Max.	
t_{AW}	Address Stable Before $\overline{WRITE}$	50		30		ns
t_{WA}	Address Hold Time for $\overline{WRITE}$	30		30		ns
t_{WW}	$\overline{WRITE}$ Pulse Width	400		300		ns
t_{DW}	Data Set Up Time for $\overline{WRITE}$	300		250		ns
t_{WD}	Data Hold Time for $\overline{WRITE}$	40		30		ns
t_{RV}	Recovery Time Between $\overline{WRITE}$ and Any Other Control Signal	1		1		μs

CLOCK AND GATE TIMING

Symbol	Parameter	8253		8253-5		Unit
		Min.	Max.	Min.	Max.	
t_{CLK}	Clock Period	380	dc	380	dc	ns
t_{PWH}	High Pulse Width	230		230		ns
t_{PWL}	Low Pulse Width	150		150		ns
t_{GW}	Gate Width High	150		150		ns
t_{GL}	Gate Width Low	100		100		ns
t_{GS}	Gate Set Up Time to CLK↑	100		100		ns
t_{GH}	Gate Hold Time After CLK↑	50		50		ns
t_{OD}	Output Delay From CLK↓[4]		400		400	ns
t_{ODG}	Output Delay From Gate↓[4]		300		300	ns
t_{WC}	Write to CLK Set Up	450		350		

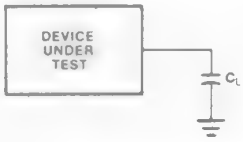
NOTES:
1. I_{OL} = 2.2 mA.
2. I_{OH} = −400 μA.
3. AC timings measured at V_{OH} 2.2, V_{OL} = 0.8.
4. C_L = 150pF.

* For Extended Temperature EXPRESS, use M8253 electrical parameters.

A.C. TESTING INPUT, OUTPUT WAVEFORM

A.C. TESTING INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0". TIMING MEASUREMENTS ARE MADE AT 2.0V FOR A LOGIC "1" AND 0.8V FOR A LOGIC "0".

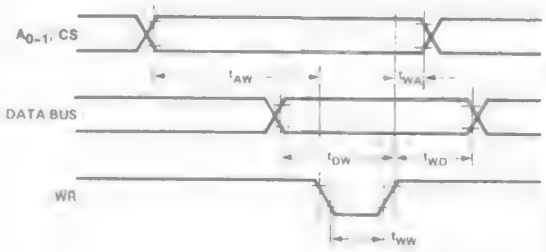
A.C. TESTING LOAD CIRCUIT



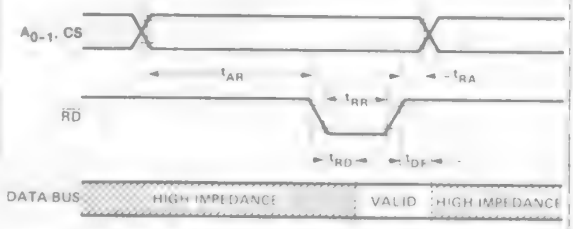
C_L INCLUDES JIG CAPACITANCE

WAVEFORMS

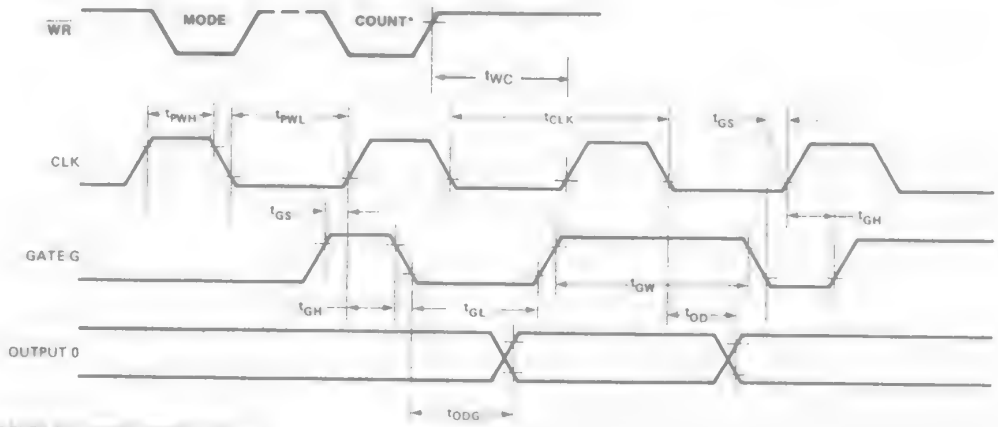
WRITE TIMING



READ TIMING



CLOCK AND GATE TIMING



*LAST BYTE OF COUNT BEING WRITTEN

PRELIMINARY

8254
PROGRAMMABLE INTERVAL TIMER

- **Compatible with Most Microprocessors Including 8080A, 8085A, iAPX 88 and iAPX 86**
- **Handles Inputs from DC to 8 MHz (10 MHz for 8254-2)**
- **Six Programmable Counter Modes**
- **Status Read-Back Command**
- **Three Independent 16-bit Counters**
- **Binary or BCD Counting**
- **Single +5V Supply**
- **Available in EXPRESS —Standard Temperature Range**

The Intel® 8254 is a counter/timer device designed to solve the common timing control problems in microcomputer system design. It provides three independent 16-bit counters, each capable of handling clock inputs up to 10 MHz. All modes are software programmable. The 8254 is a superset of the 8253.

The 8254 uses HMOS technology and comes in a 24-pin plastic or CERDIP package.

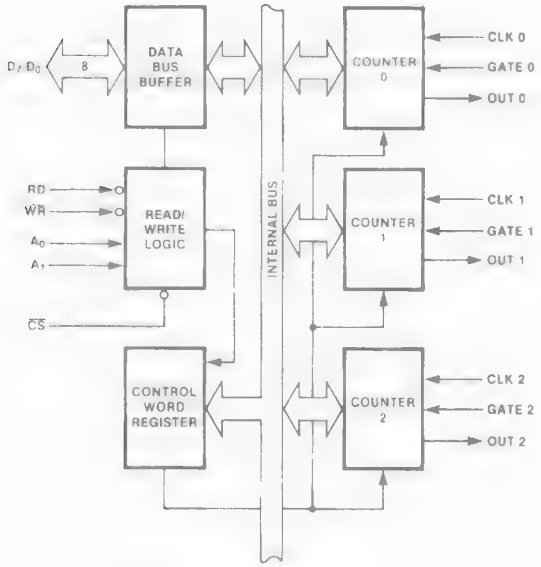


Figure 1. 8254 Block Diagram

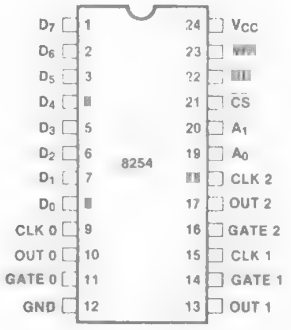


Figure 2. Pin Configuration

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
D_7-D_0	1-8	I/O	**Data:** Bi-directional three state data bus lines, connected to system data bus.
CLK 0	[illegible]	I	**Clock 0:** Clock input of Counter 0.
OUT 0	10	O	**Output 0:** Output of Counter 0.
GATE 0	11	I	**Gate 0:** Gate input of Counter 0.
GND	12		**Ground:** Power supply connection.
V_{CC}	24		**Power:** +5V power supply connection.
$\overline{WR}$	23	I	**Write Control:** This input is low during CPU write operations.
$\overline{RD}$	[illegible]	I	**Read Control:** This input is low during CPU read operations.
$\overline{CS}$	21	I	**Chip Select:** A low on this input enables the 8254 to respond to $\overline{RD}$ and $\overline{WR}$ signals. $\overline{RD}$ and $\overline{WR}$ are ignored otherwise.
A_1, A_0	20-19	I	**Address:** Used to select one of the three Counters or the Control Word Register for read or write operations. Normally connected to the system address bus.

A_1	A_0	Selects
0	0	Counter 0
0	1	Counter 1
1	0	Counter 2
1	1	Control Word Register

Symbol	Pin No.	Type	Name and Function
CLK 2	18	I	**Clock 2:** Clock input of Counter 2.
OUT 2	17	O	**Out 2:** Output of Counter 2.
GATE 2	16	I	**Gate 2:** Gate input of Counter 2.
CLK 1	15	I	**Clock 1:** Clock input of Counter 1.
GATE 1	14	I	**Gate 1:** Gate input of Counter 1.
OUT 1	13	O	**Out 1:** Output of Counter 1.

FUNCTIONAL DESCRIPTION

General

The 8254 is a programmable interval timer/counter designed for use with Intel microcomputer systems. It is a general purpose, multi-timing element that can be treated as an array of I/O ports in the system software.

The 8254 solves one of the most common problems in any microcomputer system, the generation of accurate time delays under software control. Instead of setting up timing loops in software, the programmer configures the 8254 to match his requirements and programs one of the counters for the desired delay. After the desired delay, the 8254 will interrupt the CPU. Software overhead is minimal and variable length delays can easily be accommodated.

Some of the other counter/timer functions common to microcomputers which can be implemented with the 8254 are:

- Real time clock
- Event counter
- Digital one-shot
- Programmable rate generator
- Square wave generator
- Binary rate multiplier
- Complex waveform generator
- Complex motor controller

Block Diagram

DATA BUS BUFFER

This 3-state, bi-directional, 8-bit buffer is used to interface the 8254 to the system bus (see Figure 3).

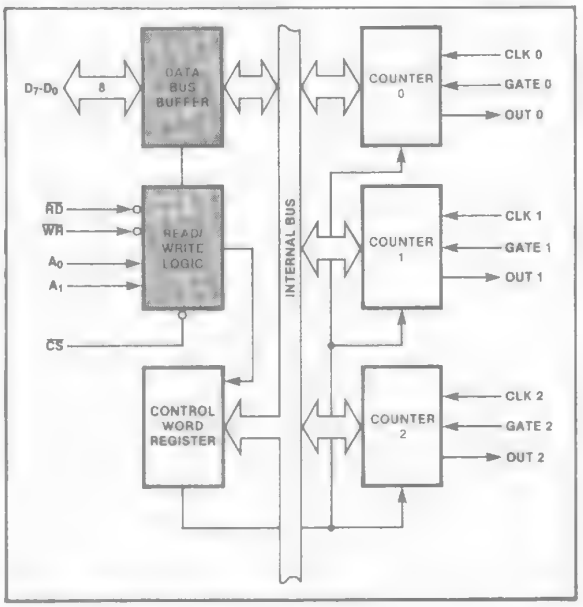


Figure 3. Block Diagram Showing Data Bus Buffer and Read/Write Logic Functions

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READ/WRITE LOGIC

The Read/Write Logic accepts inputs from the system bus and generates control signals for the other functional blocks of the 8254. A_1 and A_0 select one of the three counters or the Control Word Register to be read from/written into. A "low" on the $\overline{RD}$ input tells the 8254 that the CPU is reading one of the counters. A "low" on the $\overline{WR}$ input tells the 8254 that the CPU is writing either a Control Word or an initial count. Both $\overline{RD}$ and $\overline{WR}$ are qualified by $\overline{CS}$; $\overline{RD}$ and $\overline{WR}$ are ignored unless the 8254 has been selected by holding $\overline{CS}$ low.

CONTROL WORD REGISTER

The Control Word Register (see Figure 4) is selected by the Read/Write Logic when $A_1,A_0 = 11$. If the CPU then does a write operation to the 8254, the data is stored in the Control Word Register and is interpreted as a Control Word used to define the operation of the Counters.

The Control Word Register can only be written to; status information is available with the Read-Back Command.

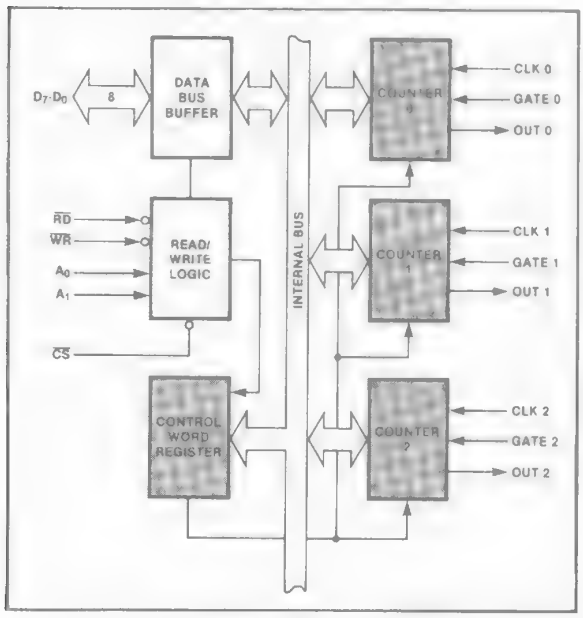

Figure 4. Block Diagram Showing Control Word Register and Counter Functions

COUNTER 0, COUNTER 1, COUNTER 2

These three functional blocks are identical in operation, so only a single Counter will be described. The internal block diagram of a single counter is shown in Figure 5.

The Counters are fully independent. Each Counter may operate in a different Mode.

The Control Word Register is shown in the figure; it is not part of the Counter itself, but its contents determine how the Counter operates.

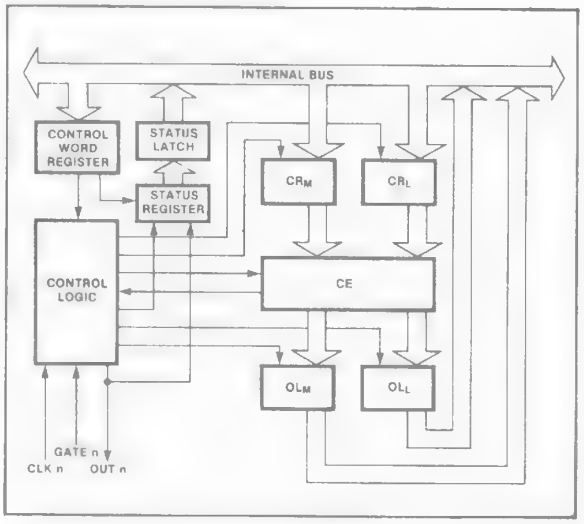

Figure 5. Internal Block Diagram of a Counter

The status register, shown in the Figure, when latched, contains the current contents of the Control Word Register and status of the output and null count flag. (See detailed explanation of the Read-Back command.)

The actual counter is labelled CE (for "Counting Element"). It is a 16-bit presettable synchronous down counter.

OL_M and OL_L are two 8-bit latches. OL stands for "Output Latch"; the subscripts M and L stand for "Most significant byte" and "Least significant byte" respectively. Both are normally referred to as one unit and called just OL. These latches normally "follow" the CE, but if a suitable Counter Latch Command is sent to the 8254, the latches "latch" the present count until read by the CPU and then return to "following" the CE. One latch at a time is enabled by the counter's Control Logic to drive the internal bus. This is how the 16-bit Counter communicates over the 8-bit internal bus. Note that the CE itself cannot be read; whenever you read the count, it is the OL that is being read.

Similarly, there are two 8-bit registers called CR_M and CR_L (for "Count Register"). Both are normally referred to as one unit and called just CR. When a new count is written to the Counter, the count is stored in the CR and later transferred to the CE. The Control Logic allows one register at a time to be loaded from the internal bus. Both bytes are transferred to the CE simultaneously. CR_M and CR_L are cleared when the Counter is programmed. In this way, if the Counter has been programmed for one byte counts (either most significant byte only or least significant byte only) the other byte will be zero. Note that the CE cannot be written into; whenever a count is written, it is written into the CR.

The Control Logic is also shown in the diagram. CLK n, GATE n, and OUT n are all connected to the outside world through the Control Logic.

8254 SYSTEM INTERFACE

The 8254 is a component of the Intel Microcomputer Systems and interfaces in the same manner as all other peripherals of the family. It is treated by the systems software as an array of peripheral I/O ports; three are counters and the fourth is a control register for MODE programming.

Basically, the select inputs A_0, A_1 connect to the A_0, A_1 address bus signals of the CPU. The CS can be derived directly from the address bus using a linear select method. Or it can be connected to the output of a decoder, such as an Intel 8205 for larger systems.

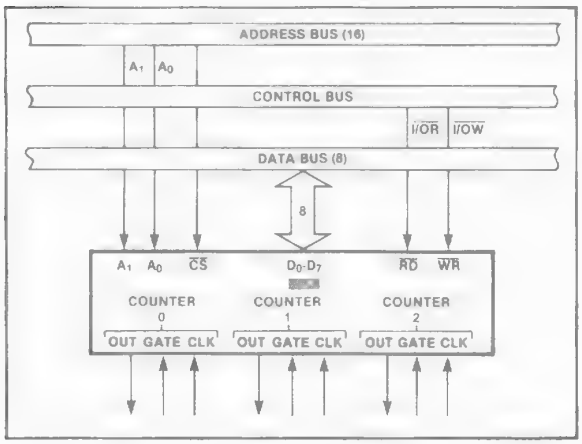

Figure 6. 8254 System Interface

OPERATIONAL DESCRIPTION

General

After power-up, the state of the 8254 is undefined. The Mode, count value, and output of all Counters are undefined.

How each Counter operates is determined when it is programmed. Each Counter must be programmed before it can be used. Unused counters need not be programmed.

Programming the 8254

Counters are programmed by writing a Control Word and then an initial count.

All Control Words are written into the Control Word Register, which is selected when $A_1,A_0 = 11$. The Control Word itself specifies which Counter is being programmed.

By contrast, initial counts are written into the Counters, not the Control Word Register. The A_1,A_0 inputs are used to select the Counter to be written into. The format of the initial count is determined by the Control Word used.

Control Word Format

$A_1,A_0 = 11$ $\overline{CS} = 0$ $\overline{RD} = 1$ $\overline{WR} = 0$

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
SC1	SC0	RW1	RW0	M2	M1	M0	BCD

SC — Select Counter:

SC1	SC0	
0	0	Select Counter 0
0	1	Select Counter 1
1	0	Select Counter 2
1	1	Read-Back Command (See Read Operations)

RW — Read/Write:

RW1	RW0	
0	0	Counter Latch Command (see Read Operations)
0	1	Read/Write least significant byte only.
1	0	Read/Write most significant byte only.
1	1	Read/Write least significant byte first, then most significant byte.

M — MODE:

M2	M1	M0	
0	0	0	Mode 0
0	0	1	Mode 1
X	1	0	Mode 2
X	1	1	Mode 3
1	0	0	Mode 4
1	0	1	Mode 5

BCD

0	Binary Counter 16-bits
1	Binary Coded Decimal (BCD) Counter (4 Decades)

NOTE: DON'T CARE BITS (X) SHOULD BE 0 TO INSURE COMPATIBILITY WITH FUTURE INTEL PRODUCTS.

Figure 7. Control Word Format

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Write Operations

The programming procedure for the 8254 is very flexible. Only two conventions need to be remembered:

1) For each Counter, the Control Word must be written before the initial count is written.
2) The initial count must follow the count format specified in the Control Word (least significant byte only, most significant byte only, or least significant byte and then most significant byte).

Since the Control Word Register and the three Counters have separate addresses (selected by the A_1,A_0 inputs), and each Control Word specifies the Counter it applies to (SC0,SC1 bits), no special instruction sequence is required. Any programming sequence that follows the conventions above is acceptable.

A new initial count may be written to a Counter at any time without affecting the Counter's programmed Mode in any way. Counting will be affected as described in the Mode definitions. The new count must follow the programmed count format.

If a Counter is programmed to read/write two-byte counts, the following precaution applies: A program must not transfer control between writing the first and second byte to another routine which also writes into that same Counter. Otherwise, the Counter will be loaded with an incorrect count.

	A_1	A_0
Control Word — Counter 0	1	1
LSB of count — Counter 0	0	0
MSB of count — Counter 0	0	0
Control Word — Counter 1	1	1
LSB of count — Counter 1	0	1
MSB of count — Counter 1	0	1
Control Word — Counter 2	1	1
LSB of count — Counter 2	1	0
MSB of count — Counter 2	1	0

	A_1	A_0
Control Word — Counter 2	1	1
Control Word — Counter 1	1	1
Control Word — Counter 0	1	1
LSB of count — Counter 2	1	0
MSB of count — Counter 2	1	0
LSB of count — Counter 1	0	1
MSB of count — Counter 1	0	1
LSB of count — Counter 0	0	0
MSB of count — Counter 0	0	0

	A_1	A_0
Control Word — Counter 0	1	1
Control Word — Counter 1	1	1
Control Word — Counter 2	1	1
LSB of count — Counter 2	1	0
LSB of count — Counter 1	0	1
LSB of count — Counter 0	0	0
MSB of count — Counter 0	0	0
MSB of count — Counter 1	0	1
MSB of count — Counter 2	1	0

	A_1	A_0
Control Word — Counter 1	1	1
Control Word — Counter 0	1	1
LSB of count — Counter 1	0	1
Control Word — Counter 2	1	1
LSB of count — Counter 0	0	0
MSB of count — Counter 1	0	1
LSB of count — Counter 2	1	0
MSB of count — Counter 0	0	0
MSB of count — Counter 2	1	0

NOTE: IN ALL FOUR EXAMPLES, ALL COUNTERS ARE PROGRAMMED TO READ/WRITE TWO-BYTE COUNTS.
THESE ARE ONLY FOUR OF MANY POSSIBLE PROGRAMMING SEQUENCES.

Figure 8. A Few Possible Programming Sequences

Read Operations

It is often desirable to read the value of a Counter without disturbing the count in progress. This is easily done in the 8254.

There are three possible methods for reading the Counters. The first is through the Read-Back command. The second is a simple read operation of the Counter, which is selected with the A_1,A_0 inputs. The only requirement is that 1) the CLK input of the selected Counter must be inhibited by using either the GATE input or external logic; or 2) the count must first be latched. Otherwise, the count may be in process of changing when it is read, giving an undefined result.

COUNTER LATCH COMMAND

The other method involves a special software command called the "Counter Latch Command". Like a Control Word, this command is written to the Control Word Register, which is selected when $A_1,A_0 = 11$. Also like a Control Word, the SC0,SC1 bits select one of the three Counters, but two other bits, D5 and D4, distinguish this command from a Control Word.

$A_1,A_0=11$; CS=0; RD=1; WR=0

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
SC1	SC0	0	0	X	X	X	X

SC1,SC0 — specify counter to be latched

SC1	SC0	Counter
0	0	0
0	1	1
1	0	2
1	1	Read-Back Command

D5,D4 — 00 designates Counter Latch Command

X — don't care

NOTE: DON'T CARE BITS (X) SHOULD BE 0 TO INSURE COMPATIBILITY WITH FUTURE INTEL PRODUCTS.

Figure 9. Counter Latching Command Format

The selected Counter's output latch (OL) latches the count at the time the Counter Latch Command is received. This count is held in the latch until it is read by the CPU (or until the Counter is reprogrammed). The count is then unlatched automatically and the OL returns to "following" the counting element (CE). This allows reading the contents of the Counters "on the fly" without affecting counting in progress. Multiple Counter Latch Commands may be used to latch more than one Counter. Each latched Counter's OL holds its count until it is read. Counter Latch Commands do not affect the programmed Mode of the Counter in any way.

If a Counter is latched and then, some time later, latched again before the count is read, the second Counter Latch Command is ignored. The count read will be the count at the time the first Counter Latch Command was issued.

With either method, the count must be read according to the programmed format; specifically, if the Counter is programmed for two byte counts, two bytes must be read. The two bytes do not have to be read one right after the other; read or write or programming operations of other Counters may be inserted between them.

Another feature of the 8254 is that reads and writes of the same Counter may be interleaved; for example, if the Counter is programmed for two byte counts, the following sequence is valid.

1. Read least significant byte.
2. Write new least significant byte.
3. Read most significant byte.
4. Write new most significant byte.

If a Counter is programmed to read/write two-byte counts, the following precaution applies: A program must not transfer control between reading the first and second byte to another routine which also reads from that same Counter. Otherwise, an incorrect count will be read.

READ-BACK COMMAND

The read-back command allows the user to check the count value, programmed Mode, and current state of the OUT pin and Null Count flag of the selected counter(s).

The command is written into the Control Word Register and has the format shown in Figure 10. The command applies to the counters selected by setting their corresponding bits D3,D2,D1=1.

A0, A1 = 11 $\overline{CS}$ = 0 $\overline{RD}$ = 1 $\overline{WR}$ = 0

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
1	1	$\overline{COUNT}$	$\overline{STATUS}$	CNT 2	CNT 1	CNT 0	0

D_5: 0 = LATCH COUNT OF SELECTED COUNTER(S)
D_4: 0 = LATCH STATUS OF SELECTED COUNTER(S)
D_3: 1 = SELECT COUNTER 2
D_2: 1 = SELECT COUNTER 1
D_1: 1 = SELECT COUNTER 0
D_0: RESERVED FOR FUTURE EXPANSION; MUST BE 0

Figure 10. Read-Back Command Format

The read-back command may be used to latch multiple counter output latches (OL) by setting the $\overline{COUNT}$ bit D5=0 and selecting the desired counter(s). This single command is functionally equivalent to several counter latch commands, one for each counter latched. Each counter's latched count is held until it is read (or the counter is reprogrammed). That counter is automatically unlatched when read, but other counters remain latched until they are read. If multiple count read-back commands are issued to the same counter without reading the count, all but the first are ignored; i.e., the count which will be read is the count at the time the first read-back command was issued.

The read-back command may also be used to latch status information of selected counter(s) by setting $\overline{STATUS}$ bit D4 = 0. Status must be latched to be read; status of a counter is accessed by a read from that counter.

The counter status format is shown in Figure 11. Bits D5 through D0 contain the counter's programmed Mode exactly as written in the last Mode Control Word. OUTPUT bit D7 contains the current state of the OUT pin. This allows the user to monitor the counter's output via software, possibly eliminating some hardware from a system.

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
OUTPUT	NULL COUNT	RW1	RW0	M2	M1	M0	

D_7 1 = OUT PIN IS 1
0 = OUT PIN IS 0
D_6 1 = NULL COUNT
0 = COUNT AVAILABLE FOR READING
D_5-D_0 COUNTER PROGRAMMED MODE (SEE FIGURE 7)

Figure 11. Status Byte

NULL COUNT bit D6 indicates when the last count written to the counter register (CR) has been loaded into the counting element (CE). The exact time this happens depends on the Mode of the counter and is described in the Mode Definitions, but until the count is loaded into the counting element (CE), it can't be read from the counter. If the count is latched or read before this time, the count value will not reflect the new count just written. The operation of Null Count is shown in Figure 12.

	THIS ACTION:	CAUSES:
A.	WRITE TO THE CONTROL WORD REGISTER:[1]	NULL COUNT=1
B.	WRITE TO THE COUNT REGISTER (CR);[2]	NULL COUNT=1
C.	NEW COUNT IS LOADED INTO CE (CR→CE);	NULL COUNT=0

[1] ONLY THE COUNTER SPECIFIED BY THE CONTROL WORD WILL HAVE ITS NULL COUNT SET TO 1. NULL COUNT BITS OF OTHER COUNTERS ARE UNAFFECTED

[2] IF THE COUNTER IS PROGRAMMED FOR TWO-BYTE COUNTS (LEAST SIGNIFICANT BYTE THEN MOST SIGNIFICANT BYTE) NULL COUNT GOES TO 1 WHEN THE SECOND BYTE IS WRITTEN.

Figure 12. Null Count Operation

If multiple status latch operations of the counter(s) are performed without reading the status, all but the first are ignored; i.e., the status that will be read is the status of the counter at the time the first status read-back command was issued.

Both count and status of the selected counter(s) may be latched simultaneously by setting both $\overline{\text{COUNT}}$ and $\overline{\text{STATUS}}$ bits D5,D4=0. This is functionally the same as issuing two separate read-back commands at once, and the above discussions apply here also. Specifically, if multiple count and/or status read-back commands are issued to the same counter(s) without any intervening reads, all but the first are ignored. This is illustrated in Figure 13.

Command D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Description	Result
1	1	0	0	0	0	1	0	Read back count and status of Counter 0	Count and status latched for Counter 0
1	1	1	0	0	1	0	0	Read back status of Counter 1	Status latched for Counter 1
1	1	1	0	1	1	0	0	Read back status of Counters 2, 1	Status latched for Counter 2, but not Counter 1
1	1	0	1	1	0	0	0	Read back count of Counter 2	Count latched for Counter 2
1	1	0	0	0	1	0	0	Read back count and status of Counter 1	Count latched for Counter 1, but not status
1	1	1	0	0	0	1	0	Read back status of Counter 1	Command ignored, status already latched for Counter 1

Figure 13. Read-Back Command Example

If both count and status of a counter are latched, the first read operation of that counter will return latched status, regardless of which was latched first. The next one or two reads (depending on whether the counter is programmed for one or two type counts) return latched count. Subsequent reads return unlatched count.

$\overline{CS}$	$\overline{RD}$	$\overline{WR}$	A_1	A_0	
0	1	0	0	0	Write into Counter 0
0	1	0	0	1	Write into Counter 1
0	1	0	1	0	Write into Counter 2
0	1	0	1	1	Write Control Word
0	0	1	0	0	Read from Counter 0
0	0	1	0	1	Read from Counter 1
0	0	1	1	0	Read from Counter 2
0	0	1	1	1	No-Operation (3-State)
1	X	X	X	X	No-Operation (3-State)
0	1	1	X	X	No-Operation (3-State)

Figure 14. Read/Write Operations Summary

Mode Definitions

The following are defined for use in describing the operation of the 8254.

CLK pulse: a rising edge, then a falling edge, in that order, of a Counter's CLK input.

trigger: a rising edge of a Counter's GATE input.

Counter loading: the transfer of a count from the CR to the CE (refer to the "Functional Description")

MODE 0: INTERRUPT ON TERMINAL COUNT

Mode 0 is typically used for event counting. After the Control Word is written, OUT is initially low, and will remain low until the Counter reaches zero. OUT then goes high and remains high until a new count or a new Mode 0 Control Word is written into the Counter.

GATE = 1 enables counting; GATE = 0 disables counting. GATE has no effect on OUT.

After the Control Word and initial count are written to a Counter, the initial count will be loaded on the next CLK pulse. This CLK pulse does not decrement the count, so for an initial count of N, OUT does not go high until N + 1 CLK pulses after the initial count is written.

If a new count is written to the Counter, it will be loaded on the next CLK pulse and counting will continue from the new count. If a two-byte count is written, the following happens:

1) Writing the first byte disables counting. OUT is set low immediately (no clock pulse required)
2) Writing the second byte allows the new count to be loaded on the next CLK pulse.

This allows the counting sequence to be synchronized by software. Again, OUT does not go high until N + 1 CLK pulses after the new count of N is written.

If an initial count is written while GATE = 0, it will still be loaded on the next CLK pulse. When GATE goes high, OUT will go high N CLK pulses later; no CLK pulse is needed to load the Counter as this has already been done.

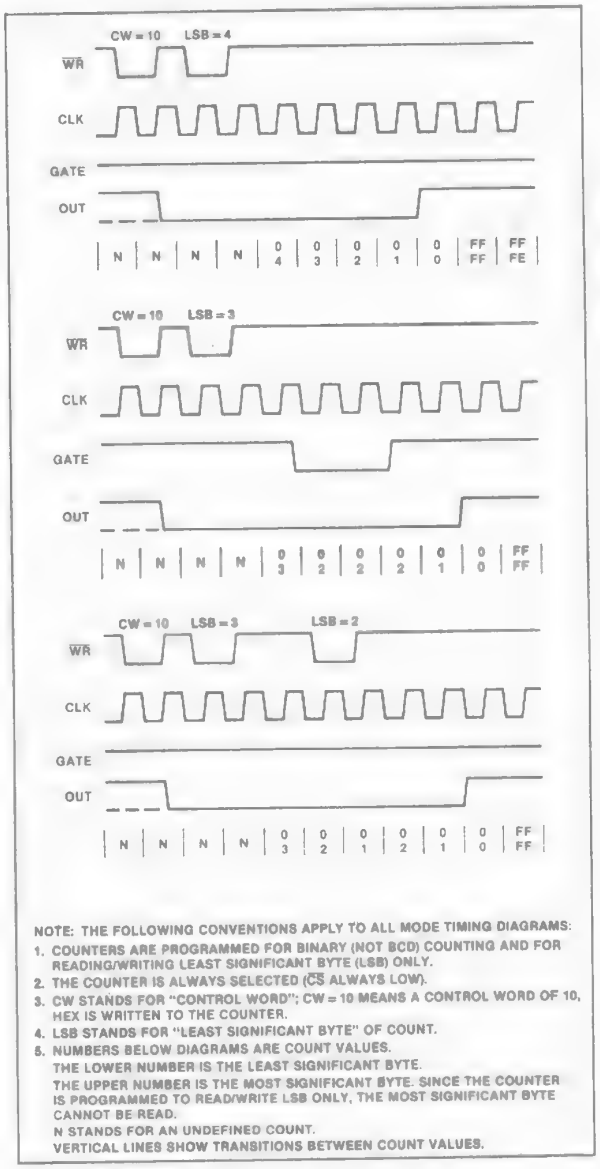


Figure 15. Mode 0

MODE 1: HARDWARE RETRIGGERABLE ONE-SHOT

OUT will be initially high. OUT will go low on the CLK pulse following a trigger to begin the one-shot pulse, and will remain low until the Counter reaches zero. OUT will then go high and remain high until the CLK pulse after the next trigger.

After writing the Control Word and initial count, the Counter is armed. A trigger results in loading the Counter and setting OUT low on the next CLK pulse, thus starting the one-shot pulse. An initial count of N will result in a one-shot pulse N CLK cycles in duration. The one-shot is retriggerable, hence OUT will remain low for N CLK pulses after any trigger. The one-shot pulse can be repeated without rewriting the same count into the counter. GATE has no effect on OUT.

If a new count is written to the Counter during a one-shot pulse, the current one-shot is not affected unless the Counter is retriggered. In that case, the Counter is loaded with the new count and the one-shot pulse continues until the new count expires.

MODE 2: RATE GENERATOR

This Mode functions like a divide-by-N counter. It is typiclaly used to generate a Real Time Clock interrupt. OUT will initially be high. When the initial count has decremented to 1, OUT goes low for one CLK pulse. OUT then goes high again, the Counter reloads the initial count and the process is repeated. Mode 2 is periodic; the same sequence is repeated indefinitely. For an initial count of N, the sequence repeats every N CLK cycles.

GATE = 1 enables counting; GATE = 0 disables counting. If GATE goes low during an output pulse, OUT is set high immediately. A trigger reloads the Counter with the initial count on the next CLK pulse; OUT goes low N CLK pulses after the trigger. Thus the GATE input can be used to synchronize the Counter.

After writing a Control Word and initial count, the Counter will be loaded on the next CLK pulse. OUT goes low N CLK Pulses after the initial count is written. This allows the Counter to be synchronized by software also.

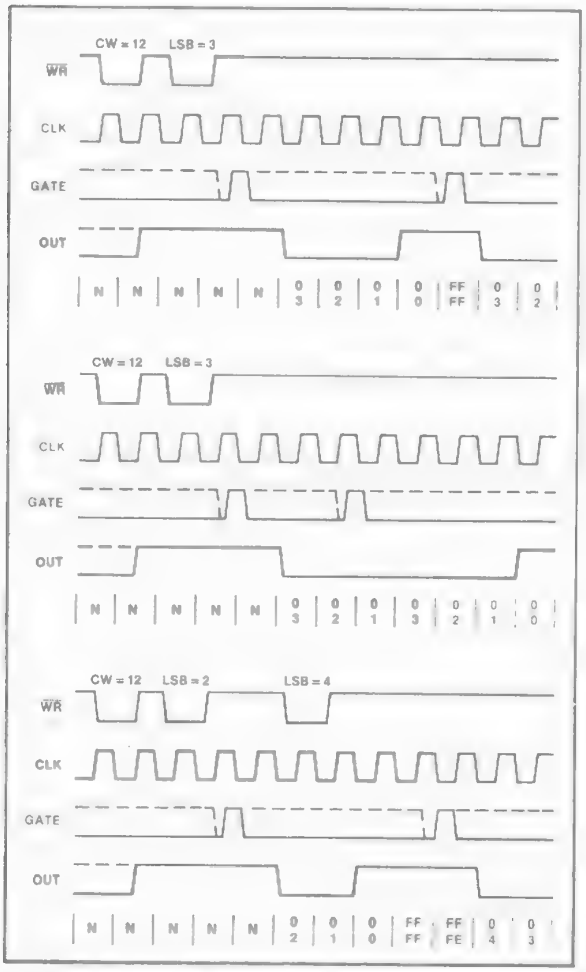
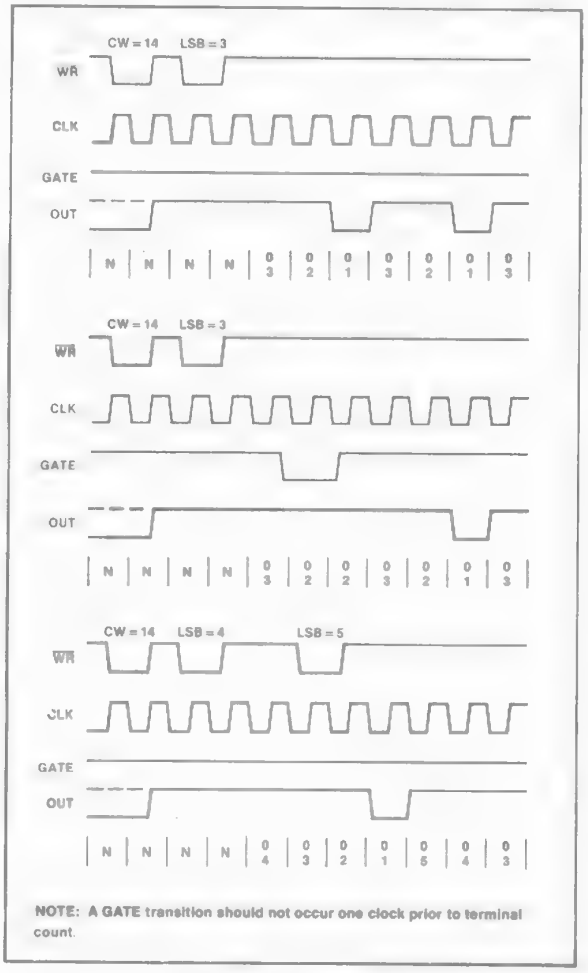


Figure 16. Mode 1



NOTE: A GATE transition should not occur one clock prior to terminal count.

Figure 17. Mode 2

Writing a new count while counting does not affect the current counting sequence. If a trigger is received after writing a new count but before the end of the current period, the Counter will be loaded with the new count on the next CLK pulse and counting will continue from the new count. Otherwise, the new count will be loaded at the end of the current counting cycle. In mode 2, a COUNT of 1 is illegal.

MODE 3: SQUARE WAVE MODE

Mode 3 is typically used for Baud rate generation. Mode 3 is similar to Mode 2 except for the duty cycle of OUT. OUT will initially be high. When half the initial count has expired, OUT goes low for the remainder of the count. Mode 3 is periodic; the sequence above is repeated indefinitely. An initial count of N results in a square wave with a period of N CLK cycles.

GATE = 1 enables counting; GATE = 0 disables counting. If GATE goes low while OUT is low, OUT is set high immediately; no CLK pulse is required. A trigger reloads the Counter with the initial count on the next CLK pulse. Thus the GATE input can be used to synchronize the Counter.

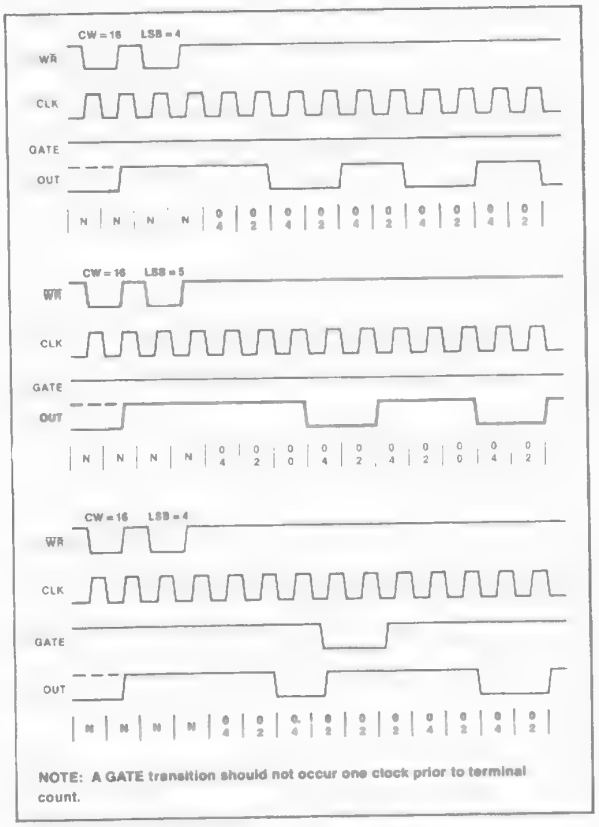
After writing a Control Word and initial count, the Counter will be loaded on the next CLK pulse. This allows the Counter to be synchronized by software also.

Writing a new count while counting does not affect the current counting sequence. If a trigger is received after writing a new count but before the end of the current half-cycle of the square wave, the Counter will be loaded with the new count on the next CLK pulse and counting will continue from the new count. Otherwise, the new count will be loaded at the end of the current half-cycle.

Mode 3 is implemented as follows:

Even counts: OUT is initially high. The initial count is loaded on one CLK pulse and then is decremented by two on succeeding CLK pulses. When the count expires OUT changes value and the Counter is reloaded with the initial count. The above process is repeated indefinitely.

Odd counts: OUT is initially high. The initial count minus one (an even number) is loaded on one CLK pulse and then is decremented by two on succeeding CLK pulses. One CLK pulse *after* the count expires, OUT goes low and the Counter is reloaded with the initial count minus one. Succeeding CLK pulses decrement the count by two. When the count expires, OUT goes high again and the Counter is reloaded with the initial count minus one. The above process is repeated indefinitely. So for odd counts, OUT will be high for (N + 1)/2 counts and low for (N − 1)/2 counts.



NOTE: A GATE transition should not occur one clock prior to terminal count.

Figure 18. Mode 3

MODE 4: SOFTWARE TRIGGERED STROBE

OUT will be initially high. When the initial count expires, OUT will go low for one CLK pulse and then go high again. The counting sequence is "triggered" by writing the initial count.

GATE = 1 enables counting; GATE = 0 disables counting. GATE has no effect on OUT.

After writing a Control Word and initial count, the Counter will be loaded on the next CLK pulse. This CLK pulse does not decrement the count, so for an initial count of N, OUT does not strobe low until N + 1 CLK pulses after the initial count is written.

If a new count is written during counting, it will be loaded on the next CLK pulse and counting will continue from the new count. If a two-byte count is written, the following happens:

1) Writing the first byte has no effect on counting.
2) Writing the second byte allows the new count to be loaded on the next CLK pulse.

This allows the sequence to be "retriggered" by software. OUT strobes low N + 1 CLK pulses after the new count of N is written.

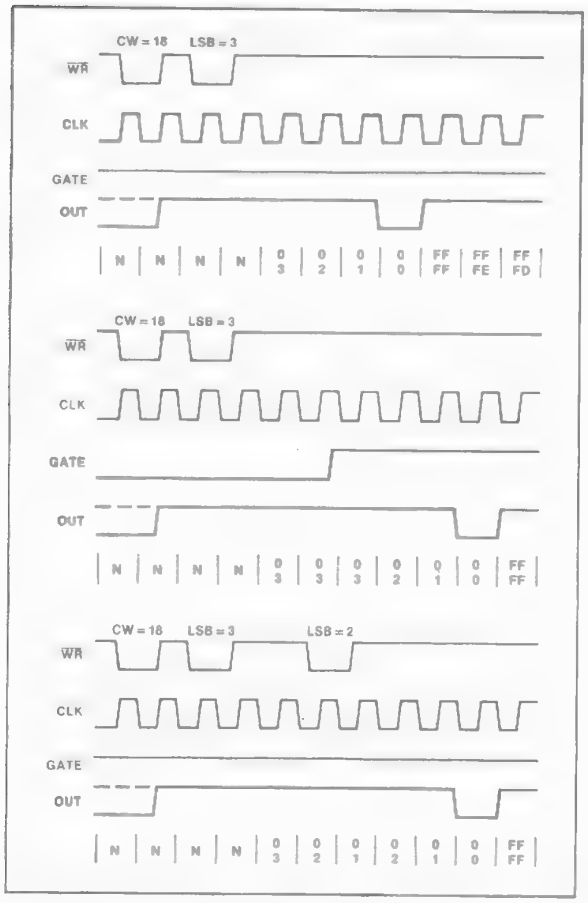


Figure 19. Mode 4

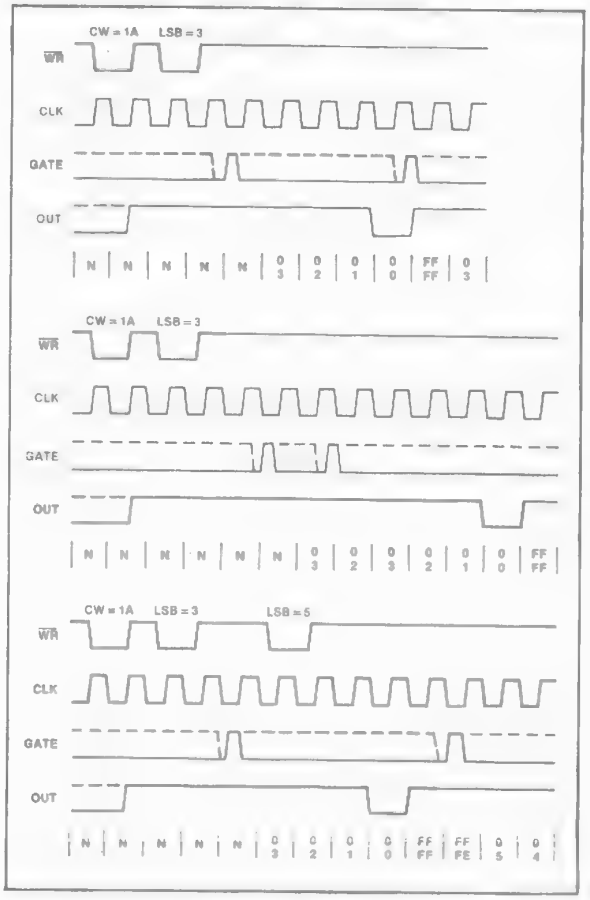


Figure 20. Mode 5

MODE 5: HARDWARE TRIGGERED STROBE (RETRIGGERABLE)

OUT will initially be high. Counting is triggered by a rising edge of GATE. When the initial count has expired, OUT will go low for one CLK pulse and then go high again.

After writing the Control Word and initial count, the counter will not be loaded until the CLK pulse after a trigger. This CLK pulse does not decrement the count, so for an initial count of N, OUT does not strobe low until N + 1 CLK pulses after a trigger.

A trigger results in the Counter being loaded with the initial count on the next CLK pulse. The counting sequence is retriggerable. OUT will not strobe low for N + 1 CLK pulses after any trigger. GATE has no effect on OUT.

If a new count is written during counting, the curent counting sequence will not be affected. If a trigger occurs after the new count is written but before the current count expires, the Counter will be loaded with the new count on the next CLK pulse and counting will continue from there.

Signal Status Modes	Low Or Going Low	Rising	High
0	Disables counting	——	Enables counting
1	——	1) Initiates counting 2) Resets output after next clock	——
2	1) Disables counting 2) Sets output immediately high	Initiates counting	Enables counting
3	1) Disables counting 2) Sets output immediately high	Initiates counting	Enables counting
4	Disables counting	——	Enables counting
5	——	Initiates counting	——

Figure 21. Gate Pin Operations Summary

Mode	Min Count	Max Count
0	1	0
1	1	0
2	2	0
3	2	0
4	1	0
5	1	0

NOTE: 0 IS EQUIVALENT TO 2^{16} FOR BINARY COUNTING AND 10^4 FOR BCD COUNTING.

Figure 22. Minimum and Maximum Initial Counts

Operation Common to All Modes

PROGRAMMING

When a Control Word is written to a Counter, all Control Logic is immediately reset and OUT goes to a known initial state; no CLK pulses are required for this.

GATE

The GATE input is always sampled on the rising edge of CLK. In Modes 0, 2, 3, and 4 the GATE input is level sensitive, and the logic level is sampled on the rising edge of CLK. In Modes 1, 2, 3, and 5 the GATE input is rising-edge sensitive. In these Modes, a rising edge of GATE (trigger) sets an edge-sensitive flip-flop in the Counter. This flip-flop is then sampled on the next rising edge of CLK; the flip-flop is reset immediately after it is sampled. In this way, a trigger will be detected no matter when it occurs—a high logic level does not have to be maintained until the next rising edge of CLK. Note that in Modes 2 and 3, the GATE input is both edge- and level-sensitive.

COUNTER

New counts are loaded and Counters are decremented on the falling edge of CLK.

The largest possible initial count is 0; this is equivalent to 2^{16} for binary counting and 10^4 for BCD counting.

The Counter does not stop when it reaches zero. In Modes 0, 1, 4, and 5 the Counter "wraps around" to the highest count, either FFFF hex for binary counting or 9999 for BCD counting, and continues counting. Modes 2 and 3 are periodic; the Counter reloads itself with the initial count and continues counting from there.

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias . . . . . 0°C to 70°C

Storage Temperature . . . . . −65°C to +150°C

Voltage on Any Pin with Respect to Ground . . . . . −0.5V to +7V

Power Dissipation . . . . . 1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to Absolute Maximum Rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ± 10%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.5V	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2.0 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400μA
I_{IL}	Input Load Current		±10	μA	V_{IN} = V_{CC} to 0V
I_{OFL}	Output Float Leakage		±10	μA	V_{OUT} = V_{CC} to 0V
I_{CC}	V_{CC} Supply Current		140	mA	

CAPACITANCE (T_A=25°C, V_{CC}=GND=0V)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
C_{IN}	Input Capacitance		10	pF	f_c = 1 MHz
$C_{I/O}$	I/O Capacitance		20	pF	Unmeasured pins returned to V_{SS}

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ± 10%, GND = 0V)

Bus Parameters (Note 1)

READ CYCLE

Symbol	Parameter	8254		8254-2		Unit
		Min.	Max.	Min.	Max.	
t_{AR}	Address Stable Before $\overline{RD}$↓	45		30		ns
t_{SR}	$\overline{CS}$ Stable Before $\overline{RD}$↓	0		0		ns
t_{RA}	Address Hold Time After $\overline{RD}$↑	0		0		ns
t_{RR}	$\overline{RD}$ Pulse Width	150		95		ns
t_{RD}	Data Delay from $\overline{RD}$↓		120		85	ns
t_{AD}	Data Delay from Address		220		185	ns
t_{DF}	$\overline{RD}$↑ to Data Floating	5	90	5	65	ns
t_{RV}	Command Recovery Time	200		165		ns

Note 1: AC timings measured at V_{OH} = 2.0V, V_{OL} = 0.8V

A.C. CHARACTERISTICS (Continued)

WRITE CYCLE

Symbol	Parameter	8254		8254-2		Unit
		Min.	Max.	Min.	Max.	
t_{AW}	Address Stable Before $\overline{WR}\downarrow$	0		0		ns
t_{SW}	$\overline{CS}$ Stable Before $\overline{WR}\downarrow$	0		0		ns
t_{WA}	Address Hold Time $\overline{WR}\uparrow$	0		0		ns
t_{WW}	$\overline{WR}$ Pulse Width	150		95		ns
t_{DW}	Data Setup Time Before $\overline{WR}\uparrow$	120		95		ns
t_{WD}	Data Hold Time After $\overline{WR}\uparrow$	0		0		ns
t_{RV}	Command Recovery Time	200		165		ns

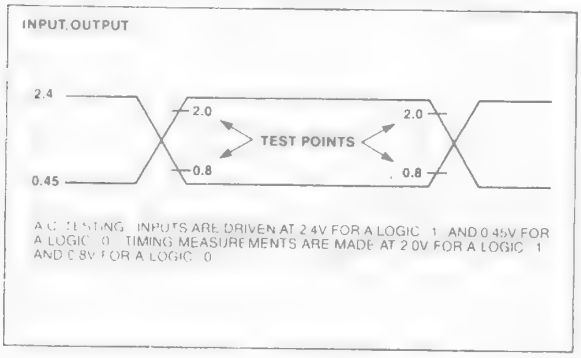
CLOCK AND GATE ($T_A = 0°C$ to $70°C$, $V_{CC} = 5V \pm 10\%$, GND = 0V)

Symbol	Parameter	8254		8254-2		Unit
		Min.	Max.	Min.	Max.	
t_{CLK}	Clock Period	125	DC	100	DC	ns
t_{PWH}	High Pulse Width	60[3]		30[3]		ns
t_{PWL}	Low Pulse Width	60[3]		50[3]		ns
t_R	Clock Rise Time		25		25	ns
t_F	Clock Fall Time		25		25	ns
t_{GW}	Gate Width High	50		50		ns
t_{GL}	Gate Width Low	50		50		ns
t_{GS}	Gate Setup Time to CLK↑	50		40		ns
t_{GH}	Gate Hold Time After CLK↑	50[2]		50[2]		ns
t_{OD}	Output Delay from CLK↓		150		100	ns
t_{ODG}	Output Delay from Gate↓		120		100	ns
t_{WC}	CLK Delay for Loading	0	55	0	55	ns
t_{WG}	Gate Delay for Sampling	−5	50	−5	40	ns
t_{WO}	OUT Delay from Mode Write		260		240	ns
t_{CL}	CLK Set Up for Count Latch	−40	45	−40	40	ns

Note 2: In Modes 1 and 5 triggers are sampled on each rising clock edge. A second trigger within 120 ns (70 ns for the 8254-2) of the rising clock edge may not be detected.

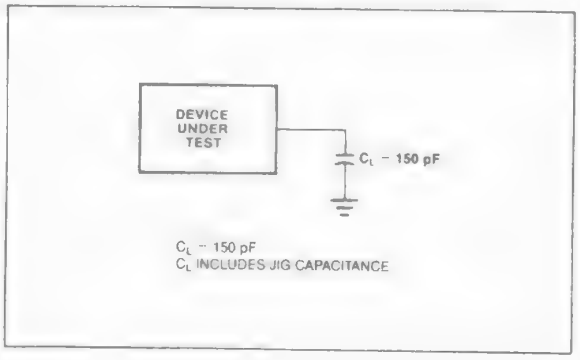
Note 3: Low-going glitches that violate t_{PWH}, t_{PWL} may cause errors requiring counter reprogramming.

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING: INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0". TIMING MEASUREMENTS ARE MADE AT 2.0V FOR A LOGIC "1" AND 0.8V FOR A LOGIC "0".

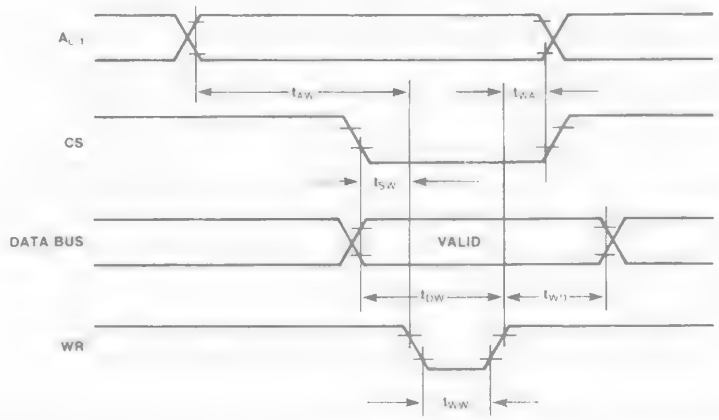
A.C. TESTING LOAD CIRCUIT



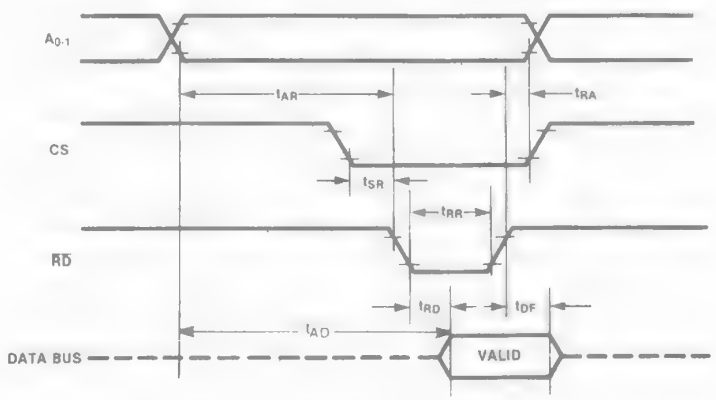
C_L = 150 pF
C_L INCLUDES JIG CAPACITANCE

WAVEFORMS

WRITE

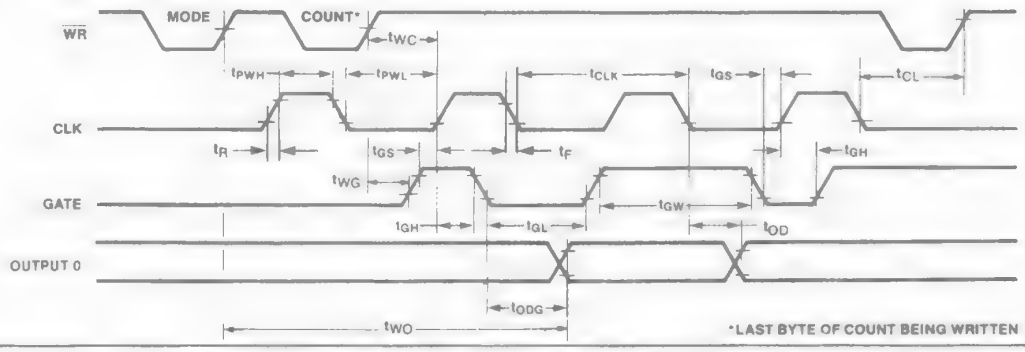


READ



RECOVERY

CLOCK AND GATE



AFN-00217D

8255A/8255A-5
PROGRAMMABLE PERIPHERAL INTERFACE

- **MCS-85™ Compatible 8255A-5**
- **24 Programmable I/O Pins**
- **Completely TTL Compatible**
- **Fully Compatible with Intel® Microprocessor Families**
- **Improved Timing Characteristics**
- **Direct Bit Set/Reset Capability Easing Control Application Interface**
- **Reduces System Package Count**
- **Improved DC Driving Capability**
- **Available in EXPRESS**
  —Standard Temperature Range
  —Extended Temperature Range

The Intel® 8255A is a general purpose programmable I/O device designed for use with Intel® microprocessors. It has 24 I/O pins which may be individually programmed in 2 groups of 12 and used in 3 major modes of operation. In the first mode (MODE 0), each group of 12 I/O pins may be programmed in sets of 4 to be input or output. In MODE 1, the second mode, each group may be programmed to have 8 lines of input or output. Of the remaining 4 pins, 3 are used for handshaking and interrupt control signals. The third mode of operation (MODE 2) is a bidirectional bus mode which uses 8 lines for a bidirectional bus, and 5 lines, borrowing one from the other group, for handshaking.

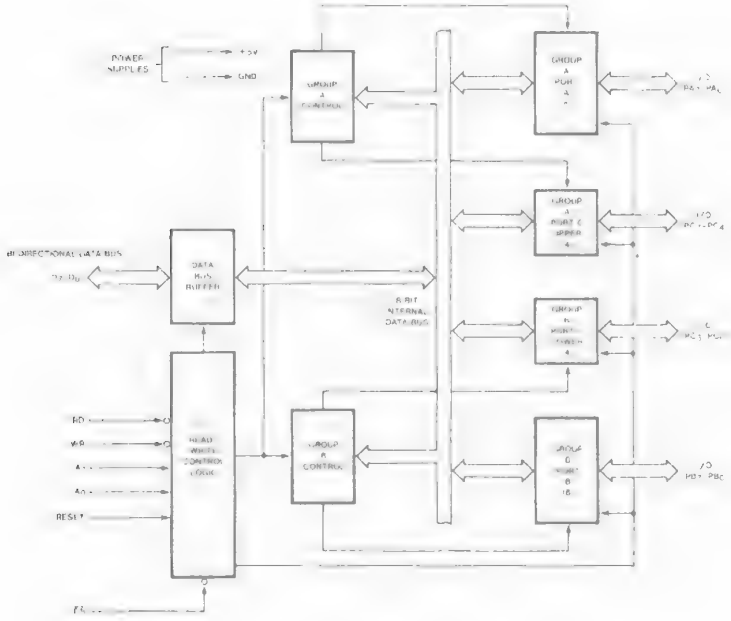


Figure 1. 8255A Block Diagram

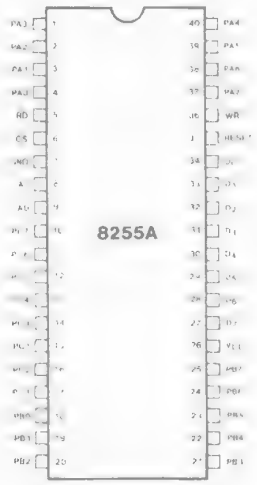


Figure 2. Pin Configuration

*INTEL CORPORATION, 1982

8255A FUNCTIONAL DESCRIPTION

General

The 8255A is a programmable peripheral interface (PPI) device designed for use in Intel® microcomputer systems. Its function is that of a general purpose I/O component to interface peripheral equipment to the microcomputer system bus. The functional configuration of the 8255A is programmed by the system software so that normally no external logic is necessary to interface peripheral devices or structures.

Data Bus Buffer

This 3-state bidirectional 8-bit buffer is used to interface the 8255A to the system data bus. Data is transmitted or received by the buffer upon execution of input or output instructions by the CPU. Control words and status information are also transferred through the data bus buffer.

Read/Write and Control Logic

The function of this block is to manage all of the internal and external transfers of both Data and Control or Status words. It accepts inputs from the CPU Address and Control busses and in turn, issues commands to both of the Control Groups.

($\overline{CS}$)

Chip Select. A "low" on this input pin enables the communiction between the 8255A and the CPU.

($\overline{RD}$)

Read. A "low" on this input pin enables the 8255A to send the data or status information to the CPU on the data bus. In essence, it allows the CPU to "read from" the 8255A.

($\overline{WR}$)

Write. A "low" on this input pin enables the CPU to write data or control words into the 8255A.

(A_0 and A_1)

Port Select 0 and Port Select 1. These input signals, in conjunction with the RD and WR inputs, control the selection of one of the three ports or the control word registers. They are normally connected to the least significant bits of the address bus (A_0 and A_1).

8255A BASIC OPERATION

A_1	A_0	$\overline{RD}$	$\overline{WR}$	$\overline{CS}$	INPUT OPERATION (READ)
0	0	0	1	0	PORT A → DATA BUS
0	1	0	1	0	PORT B → DATA BUS
1	0	0	1	0	PORT C → DATA BUS
					OUTPUT OPERATION (WRITE)
0	0	1	0	0	DATA BUS → PORT A
0	1	1	0	0	DATA BUS → PORT B
1	0	1	0	0	DATA BUS → PORT C
1	1	1	0	0	DATA BUS → CONTROL
					DISABLE FUNCTION
X	X	X	X	1	DATA BUS → 3-STATE
1	1	0	1	0	ILLEGAL CONDITION
X	X	1	1	0	DATA BUS → 3-STATE

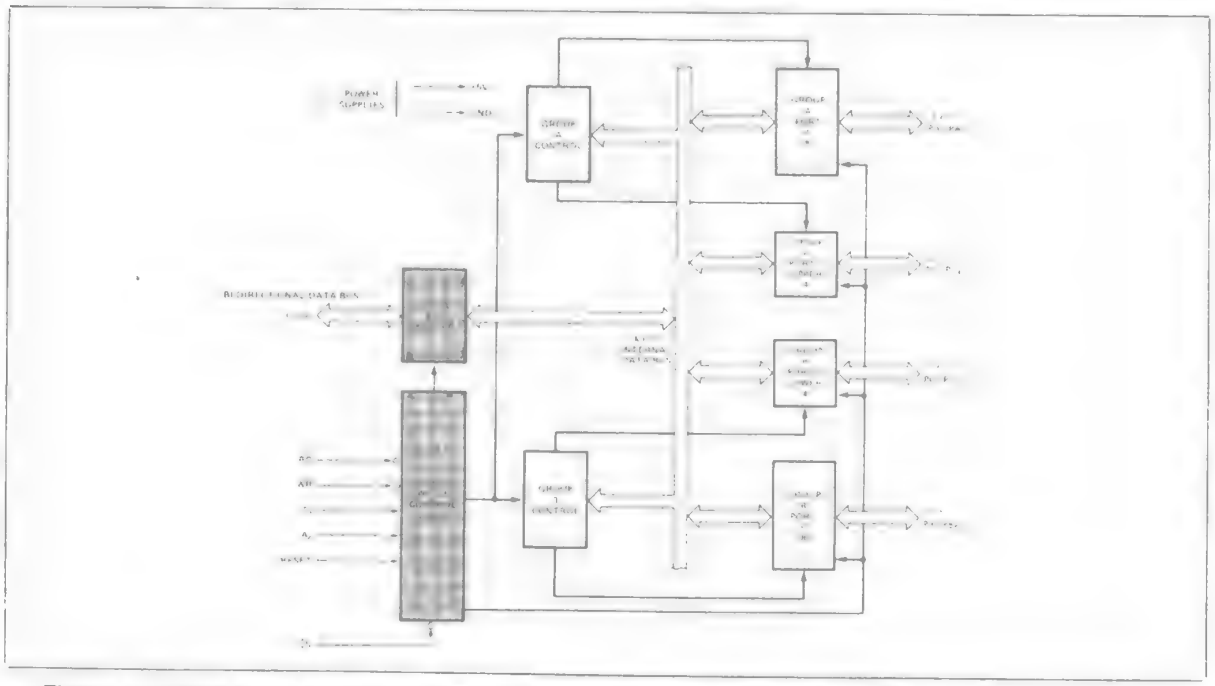


Figure 3. 8255A Block Diagram Showing Data Bus Buffer and Read/Write Control Logic Functions

(RESET)

Reset. A "high" on this input clears the control register and all ports (A, B, C) are set to the input mode.

Group A and Group B Controls

The functional configuration of each port is programmed by the systems software. In essence, the CPU "outputs" a control word to the 8255A. The control word contains information such as "mode", "bit set", "bit reset", etc., that initializes the functional configuration of the 8255A.

Each of the Control blocks (Group A and Group B) accepts "commands" from the Read/Write Control Logic, receives "control words" from the internal data bus and issues the proper commands to its associated ports.

Control Group A – Port A and Port C upper (C7-C4)
Control Group B – Port B and Port C lower (C3-C0)

The Control Word Register can Only be written into. No Read operation of the Control Word Register is allowed.

Ports A, B, and C

The 8255A contains three 8-bit ports (A, B, and C). All can be configured in a wide variety of functional characteristics by the system software but each has its own special features or "personality" to further enhance the power and flexibility of the 8255A.

Port A. One 8-bit data output latch/buffer and one 8-bit data input latch.

Port B. One 8-bit data input/output latch/buffer and one 8-bit data input buffer.

Port C. One 8-bit data output latch/buffer and one 8-bit data input buffer (no latch for input). This port can be divided into two 4-bit ports under the mode control. Each 4-bit port contains a 4-bit latch and it can be used for the control signal outputs and status signal inputs in conjunction with ports A and B.

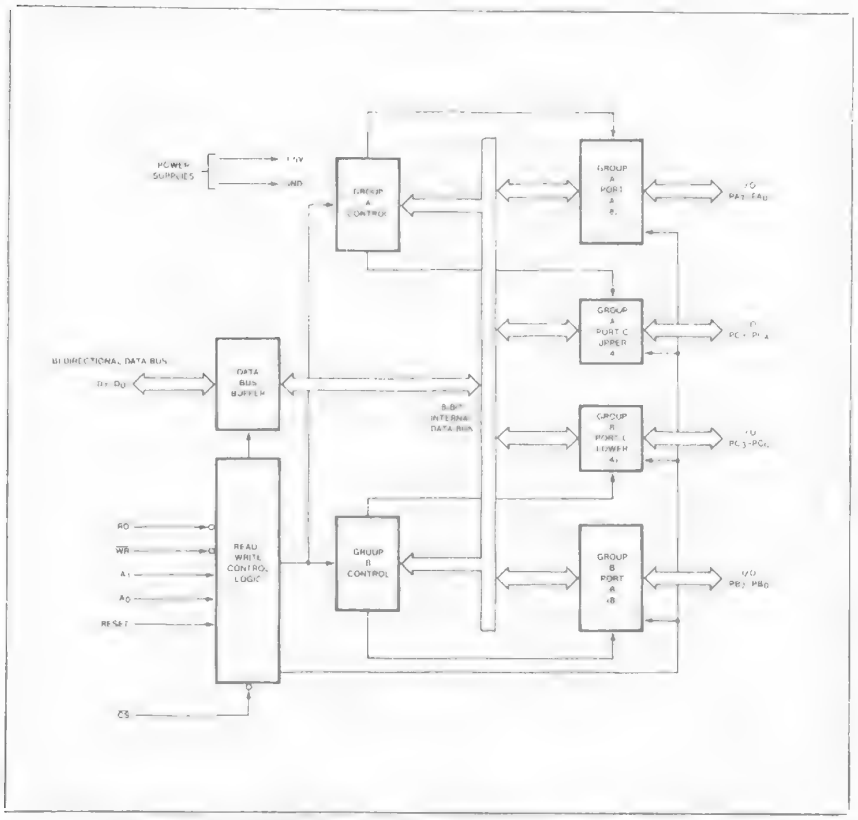
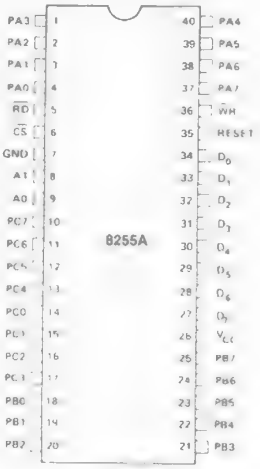


Figure 4. 8225A Block Diagram Showing Group A and Group B Control Functions

PIN CONFIGURATION



PIN NAMES

D_7–D_0	DATA BUS (BI-DIRECTIONAL)
RESET	RESET INPUT
$\overline{CS}$	CHIP SELECT
$\overline{RD}$	READ INPUT
$\overline{WR}$	WRITE INPUT
A0, A1	PORT ADDRESS
PA7-PA0	PORT A (BIT)
PB7-PB0	PORT B (BIT)
PC7-PC0	PORT C (BIT)
V_{CC}	+5 VOLTS
GND	Ø VOLTS

8255A OPERATIONAL DESCRIPTION

Mode Selection

There are three basic modes of operation that can be selected by the system software:

Mode 0 — Basic Input/Output
Mode 1 — Strobed Input/Output
Mode 2 — Bi-Directional Bus

When the reset input goes "high" all ports will be set to the input mode (i.e., all 24 lines will be in the high impedance state). After the reset is removed the 8255A can remain in the input mode with no additional initialization required. During the execution of the system program any of the other modes may be selected using a single output instruction. This allows a single 8255A to service a variety of peripheral devices with a simple software maintenance routine.

The modes for Port A and Port B can be separately defined, while Port C is divided into two portions as required by the Port A and Port B definitions. All of the output registers, including the status flip-flops, will be reset whenever the mode is changed. Modes may be combined so that their functional definition can be "tailored" to almost any I/O structure. For instance; Group B can be programmed in Mode 0 to monitor simple switch closings or display computational results, Group A could be programmed in Mode 1 to monitor a keyboard or tape reader on an interrupt-driven basis.

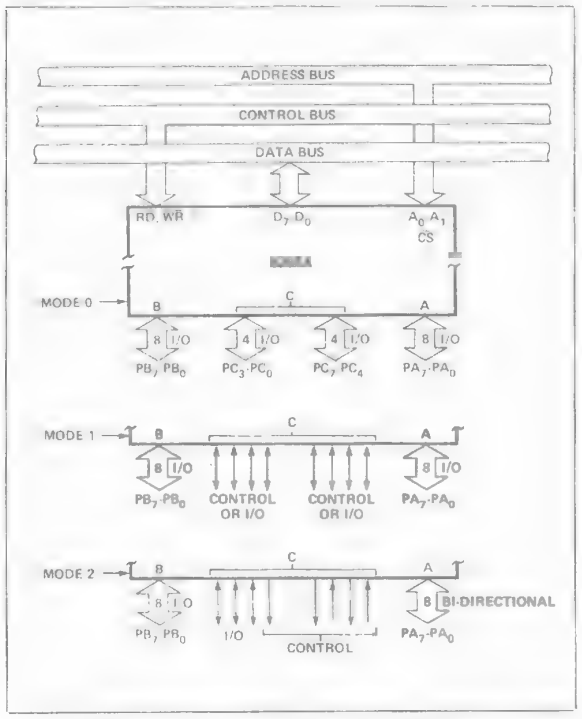


Figure 5. Basic Mode Definitions and Bus Interface

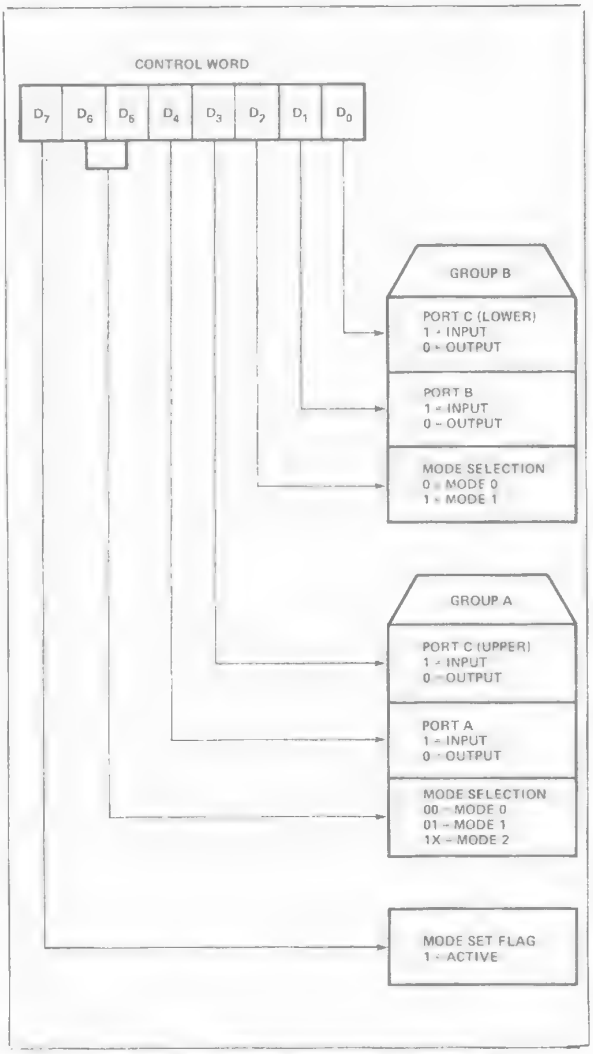


Figure 6. Mode Definition Format

The mode definitions and possible mode combinations may seem confusing at first but after a cursory review of the complete device operation a simple, logical I/O approach will surface. The design of the 8255A has taken into account things such as efficient PC board layout, control signal definition vs PC layout and complete functional flexibility to support almost any peripheral device with no external logic. Such design represents the maximum use of the available pins.

Single Bit Set/Reset Feature

Any of the eight bits of Port C can be Set or Reset using a single OUTput instruction. This feature reduces software requirements in Control-based applications.

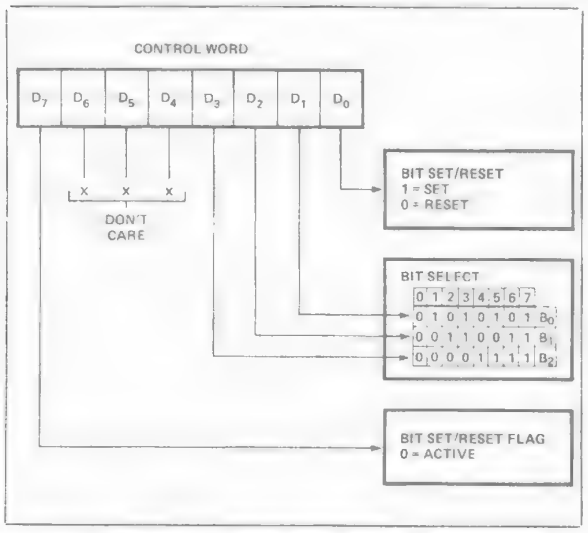


Figure 7. Bit Set/Reset Format

When Port C is being used as status/control for Port A or B, these bits can be set or reset by using the Bit Set/Reset operation just as if they were data output ports.

Interrupt Control Functions

When the 8255A is programmed to operate in mode 1 or mode 2, control signals are provided that can be used as interrupt request inputs to the CPU. The interrupt request signals, generated from port C, can be inhibited or enabled by setting or resetting the associated INTE flip-flop, using the bit set/reset function of port C.

This function allows the Programmer to disallow or allow a specific I/O device to interrupt the CPU without affecting any other device in the interrupt structure.

INTE flip-flop definition:

(BIT-SET) — INTE is SET — Interrupt enable
(BIT-RESET) — INTE is RESET — Interrupt disable

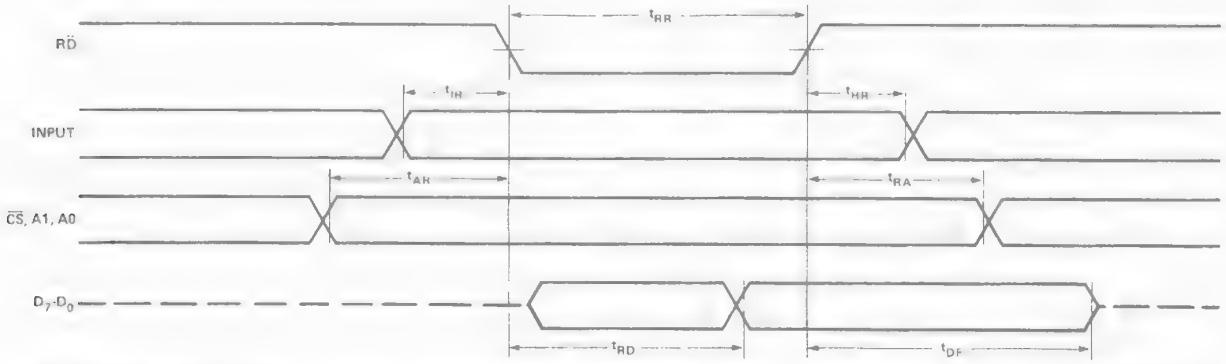
Note: All Mask flip-flops are automatically reset during mode selection and device Reset.

Operating Modes

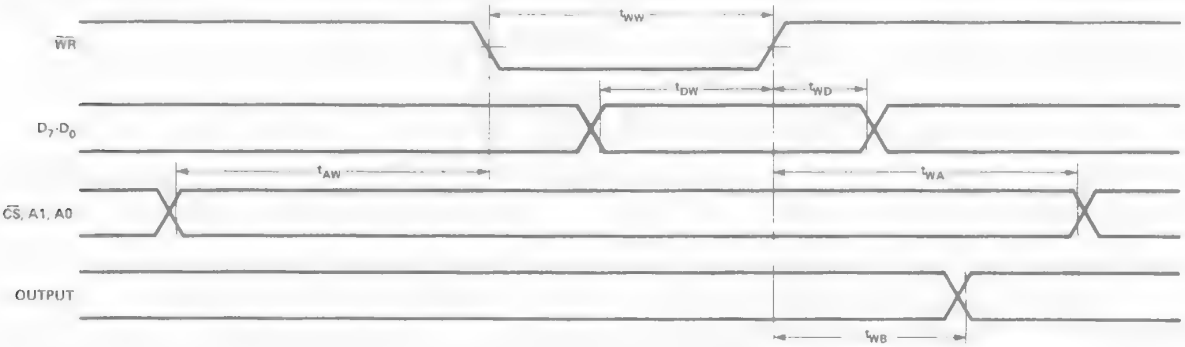
MODE 0 (Basic Input/Output). This functional configuration provides simple input and output operations for each of the three ports. No "handshaking" is required, data is simply written to or read from a specified port.

Mode 0 Basic Functional Definitions:

- Two 8-bit ports and two 4-bit ports.
- Any port can be input or output.
- Outputs are latched.
- Inputs are not latched.
- 16 different Input/Output configurations are possible in this Mode.



MODE 0 (Basic Input)

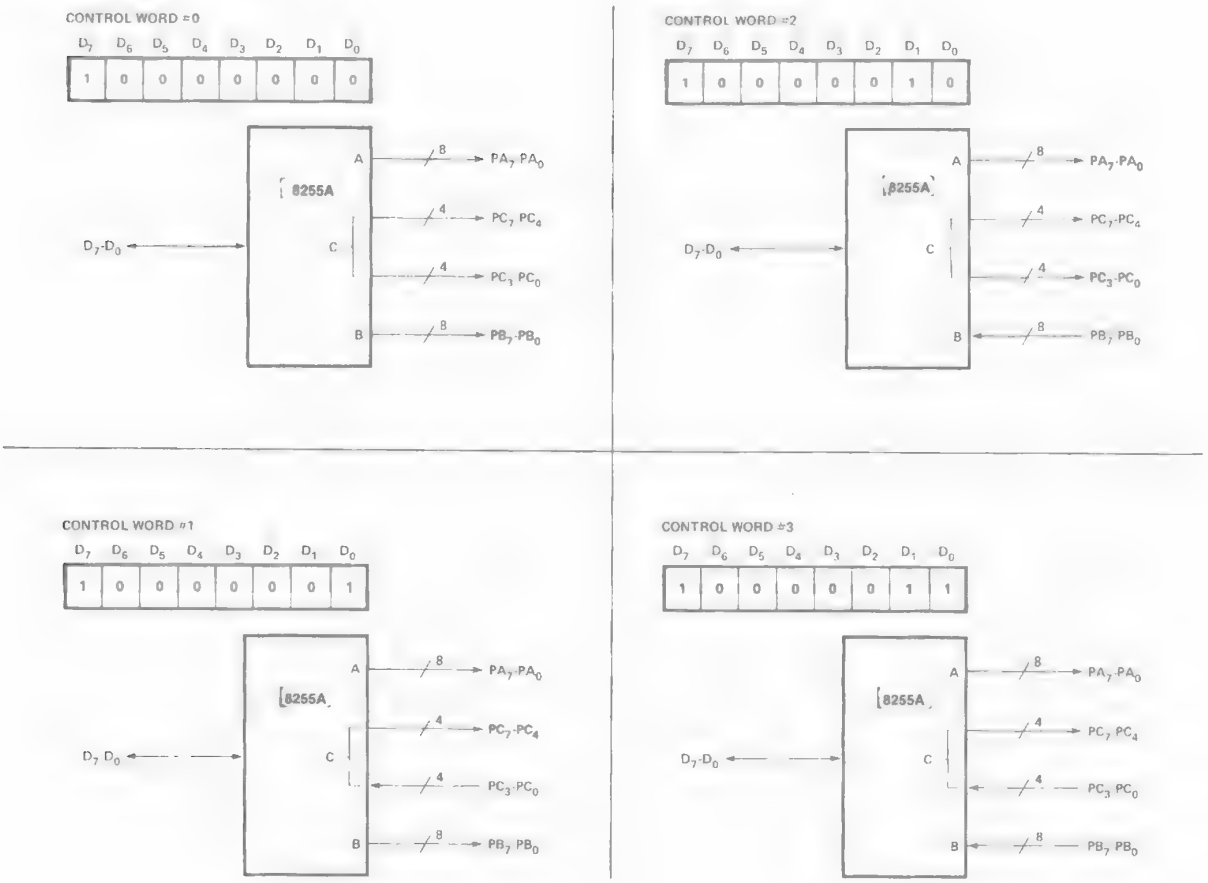


MODE 0 (Basic Output)

MODE 0 Port Definition

A		B		GROUP A			GROUP B	
D_4	D_3	D_1	D_0	PORT A	PORT C (UPPER)	#	PORT B	PORT C (LOWER)
0	0	0	0	OUTPUT	OUTPUT	0	OUTPUT	OUTPUT
0	0	0	1	OUTPUT	OUTPUT	1	OUTPUT	INPUT
0	0	1	0	OUTPUT	OUTPUT	2	INPUT	OUTPUT
0	0	1	1	OUTPUT	OUTPUT	3	INPUT	INPUT
0	1	0	0	OUTPUT	INPUT	4	OUTPUT	OUTPUT
0	1	0	1	OUTPUT	INPUT	5	OUTPUT	INPUT
0	1	1	0	OUTPUT	INPUT	6	INPUT	OUTPUT
0	1	1	1	OUTPUT	INPUT	7	INPUT	INPUT
1	0	0	0	INPUT	OUTPUT	8	OUTPUT	OUTPUT
1	0	0	1	INPUT	OUTPUT	9	OUTPUT	INPUT
1	0	1	0	INPUT	OUTPUT	10	INPUT	OUTPUT
1	0	1	1	INPUT	OUTPUT	11	INPUT	INPUT
1	1	0	0	INPUT	INPUT	12	OUTPUT	OUTPUT
1	1	0	1	INPUT	INPUT	13	OUTPUT	INPUT
1	1	1	0	INPUT	INPUT	14	INPUT	OUTPUT
1	1	1	1	INPUT	INPUT	15	INPUT	INPUT

MODE 0 Configurations



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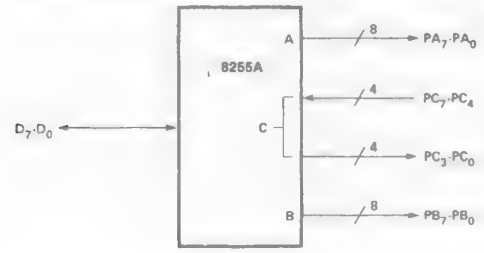
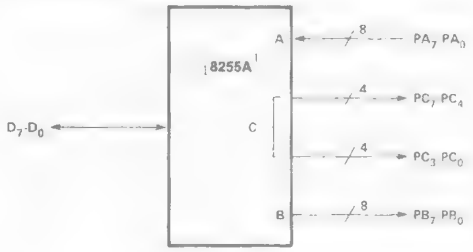
CONTROL WORD #4

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
1	0	0	0	1	0	0	0



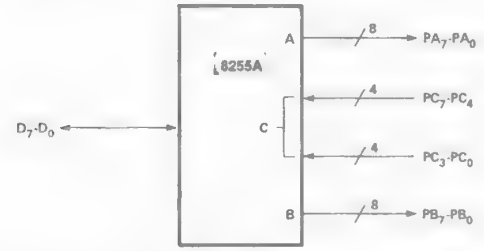
CONTROL WORD #8

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
1	0	0	1	0	0	0	0



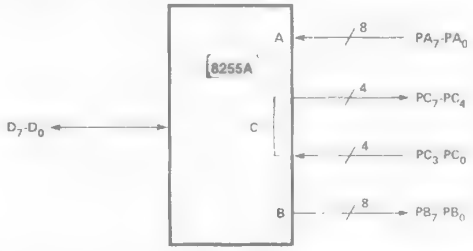
CONTROL WORD #5

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
1	0	0	0	1	0	0	1



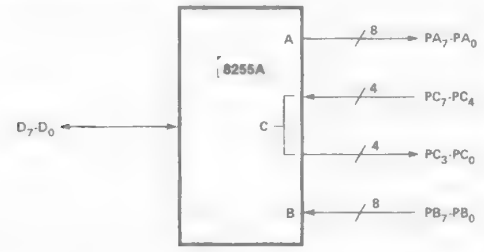
CONTROL WORD #9

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
1	0	0	1	0	0	0	1



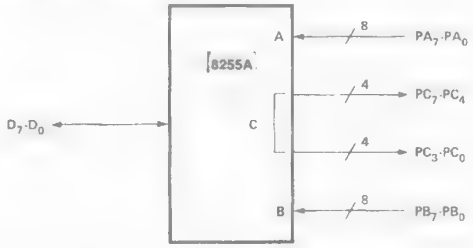
CONTROL WORD #6

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
1	0	0	0	1	0	1	0



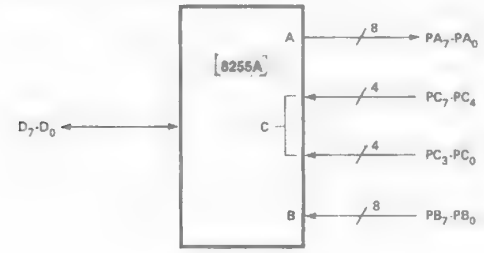
CONTROL WORD #10

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
1	0	0	1	0	0	1	0



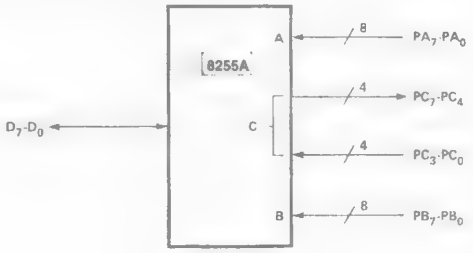
CONTROL WORD #7

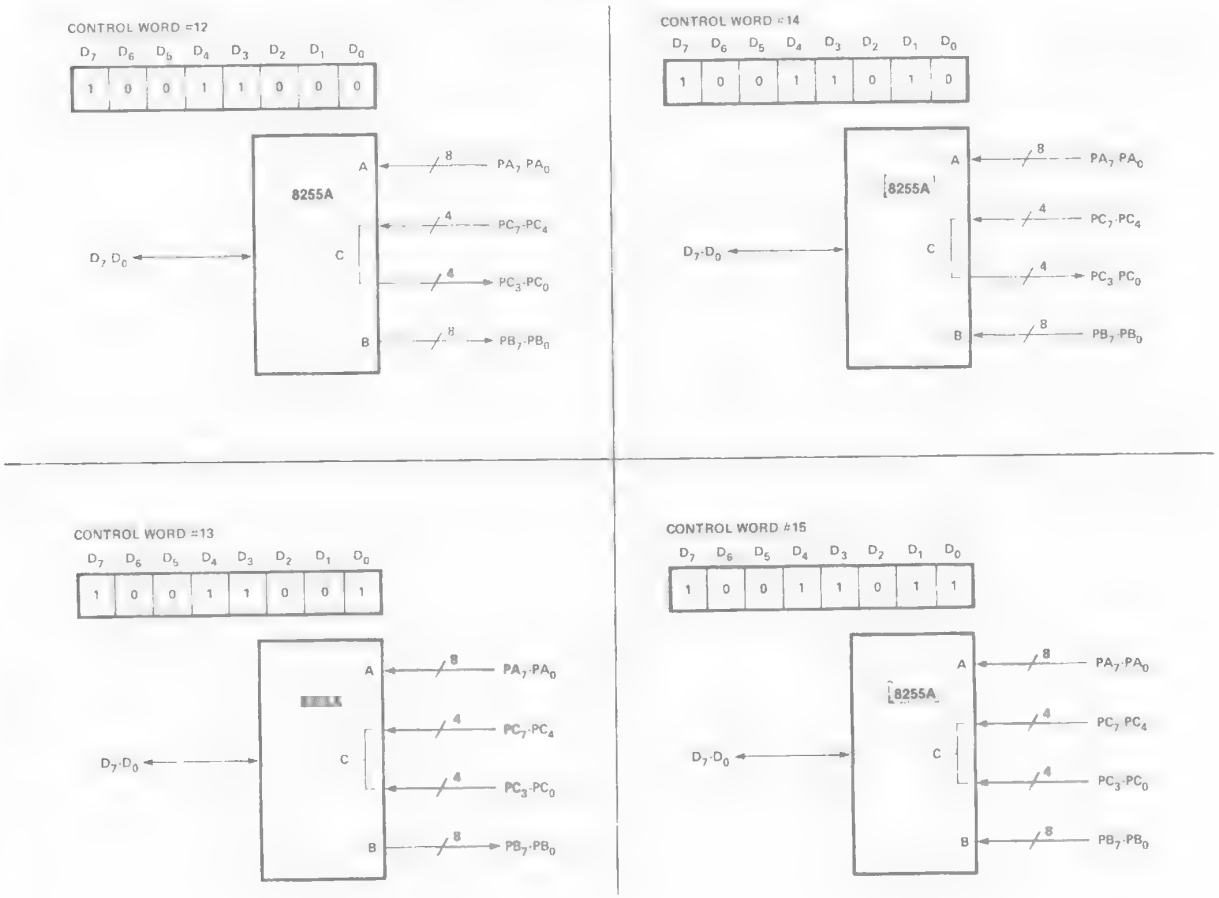
D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
1	0	0	0	1	0	1	1



CONTROL WORD #11

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
1	0	0	1	0	0	1	1





Operating Modes

MODE 1 (Strobed Input/Output). This functional configuration provides a means for transferring I/O data to or from a specified port in conjunction with strobes or "handshaking" signals. In mode 1, port A and Port B use the lines on port C to generate or accept these "handshaking" signals.

Mode 1 Basic Functional Definitions:

- Two Groups (Group A and Group B)
- Each group contains one 8-bit data port and one 4-bit control/data port.
- The 8-bit data port can be either input or output. Both inputs and outputs are latched.
- The 4-bit port is used for control and status of the 8-bit data port.

Input Control Signal Definition

STB (Strobe Input). A "low" on this input loads data into the input latch.

IBF (Input Buffer Full F/F)

A "high" on this output indicates that the data has been loaded into the input latch; in essence, an acknowledgement. IBF is set by STB input being low and is reset by the rising edge of the RD input.

INTR (Interrupt Request)

A "high" on this output can be used to interrupt the CPU when an input device is requesting service. INTR is set by the $\overline{STB}$ is a "one", IBF is a "one" and INTE is a "one". It is reset by the falling edge of $\overline{RD}$. This procedure allows an input device to request service from the CPU by simply strobing its data into the port.

INTE A

Controlled by bit set/reset of PC_4.

INTE B

Controlled by bit set/reset of PC_2.

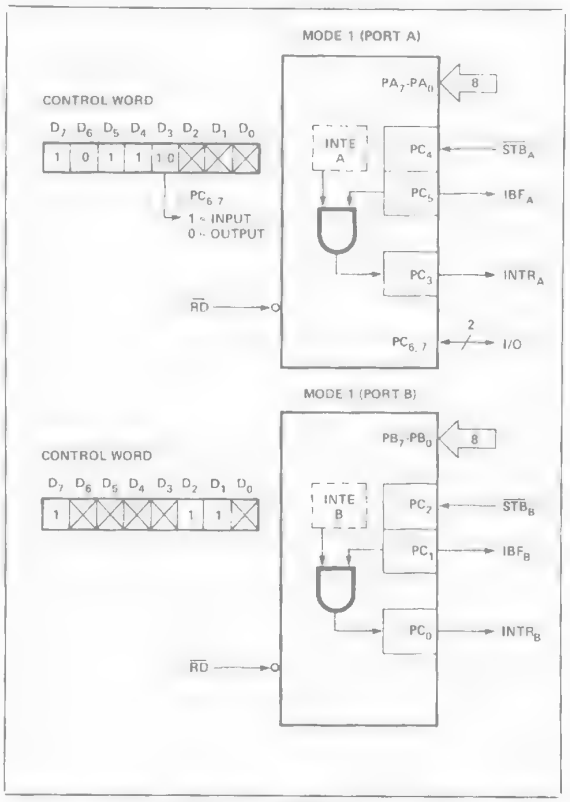


Figure 8. MODE 1 Input

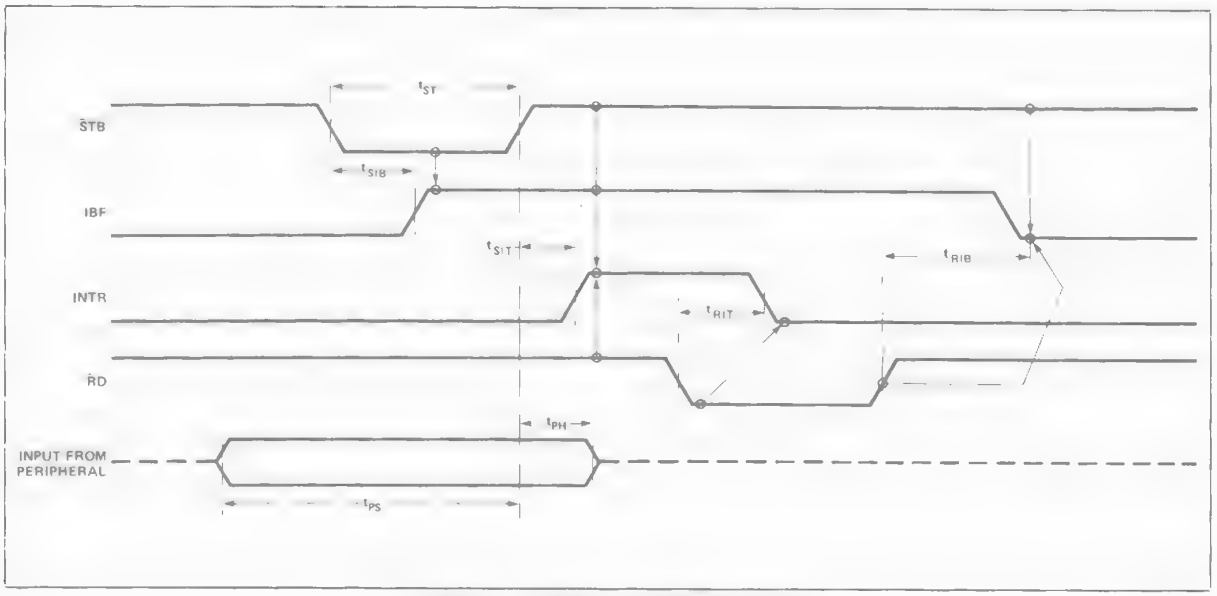


Figure 9. MODE 1 (Strobed Input)

Output Control Signal Definition

$\overline{OBF}$ (Output Buffer Full F/F). The OBF output will go "low" to indicate that the CPU has written data out to the specified port. The OBF F/F will be set by the rising edge of the WR input and reset by ACK input being low.

$\overline{ACK}$ (Acknowledge Input). A "low" on this input informs the 8255A that the data from port A or port B has been accepted. In essence, a response from the peripheral device indicating that it has received the data output by the CPU.

INTR (Interrupt Request). A "high" on this output can be used to interrupt the CPU when an output device has accepted data transmitted by the CPU. INTR is set when ACK is a "one", OBF is a "one" and INTE is a "one". It is reset by the falling edge of WR.

INTE A

Controlled by bit set/reset of PC_6.

INTE B

Controlled by bit set/reset of PC_2.

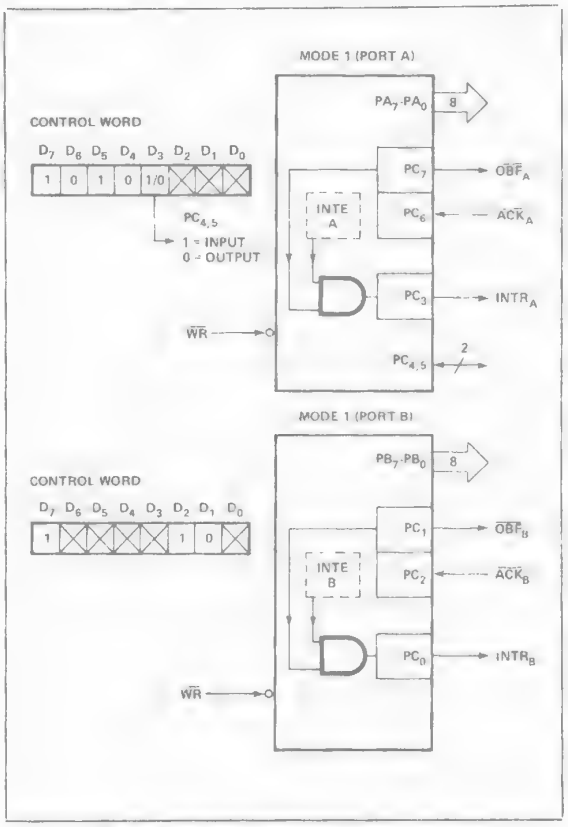


Figure 10. MODE 1 Output

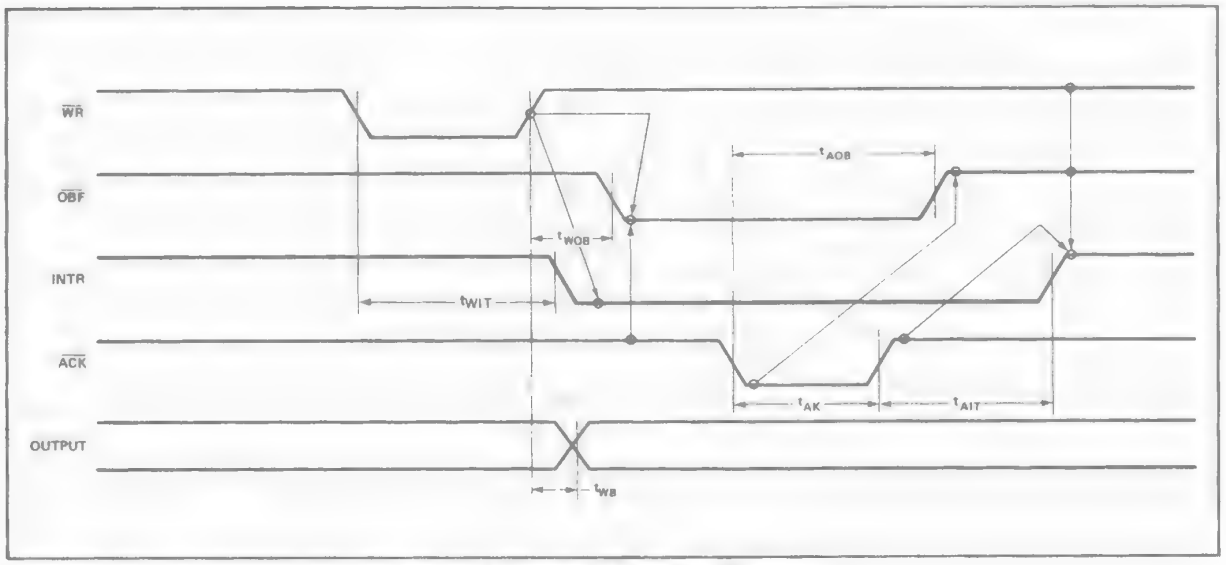


Figure 11. Mode 1 (Strobed Output)

Combinations of MODE 1

Port A and Port B can be individually defined as input or output in Mode 1 to support a wide variety of strobed I/O applications.

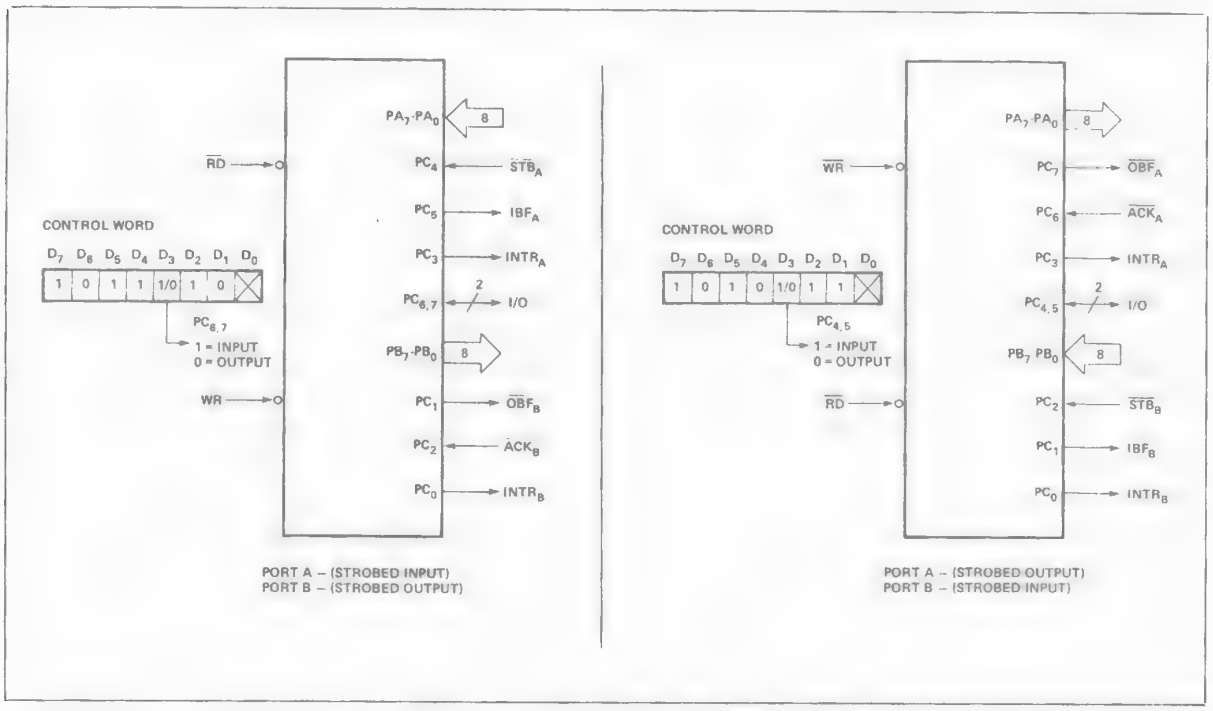


Figure 12. Combinations of MODE 1

Operating Modes

MODE 2 (Strobed Bidirectional Bus I/O). This functional configuration provides a means for communicating with a peripheral device or structure on a single 8-bit bus for both transmitting and receiving data (bidirectional bus I/O). "Handshaking" signals are provided to maintain proper bus flow discipline in a similar manner to MODE 1. Interrupt generation and enable/disable functions are also available.

MODE 2 Basic Functional Definitions:

- Used in Group A only.
- One 8-bit, bi-directional bus Port (Port A) and a 5-bit control Port (Port C).
- Both inputs and outputs are latched.
- The 5-bit control port (Port C) is used for control and status for the 8-bit, bi-directional bus port (Port A).

Bidirectional Bus I/O Control Signal Definition

INTR (Interrupt Request). A high on this output can be used to interrupt the CPU for both input or output operations.

Output Operations

$\overline{OBF}$ (Output Buffer Ful). The OBF output will go "low" to indicate that the CPU has written data out to port A.

$\overline{ACK}$ (Acknowledge). A "low" on this input enables the tri-state output buffer of port A to send out the data. Otherwise, the output buffer will be in the high impedance state.

INTE 1 (The INTE Flip-Flop Associated with OBF). Controlled by bit set/reset of PC_6.

Input Operations

$\overline{STB}$ (Strobe Input)

STB (Strobe Input). A "low" on this input loads data into the input latch.

IBF (Input Buffer Full F/F). A "high" on this output indicates that data has been loaded into the input latch.

INTE 2 (The INTE Flip-Flop Associated with IBF). Controlled by bit set/reset of PC_4.

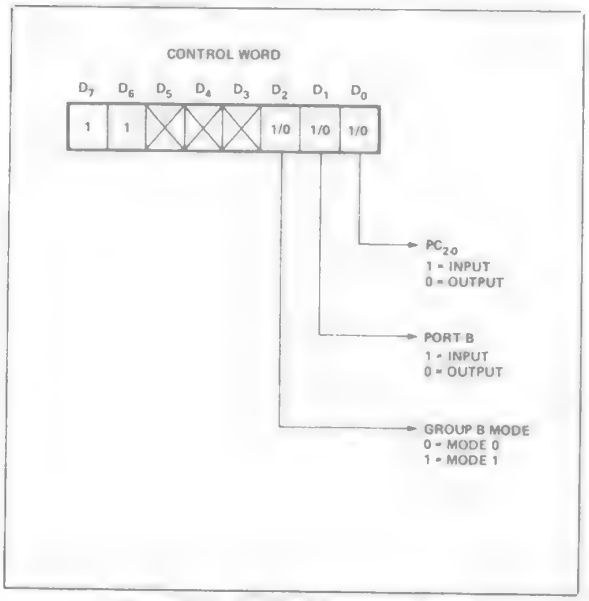


Figure 13. MODE Control Word

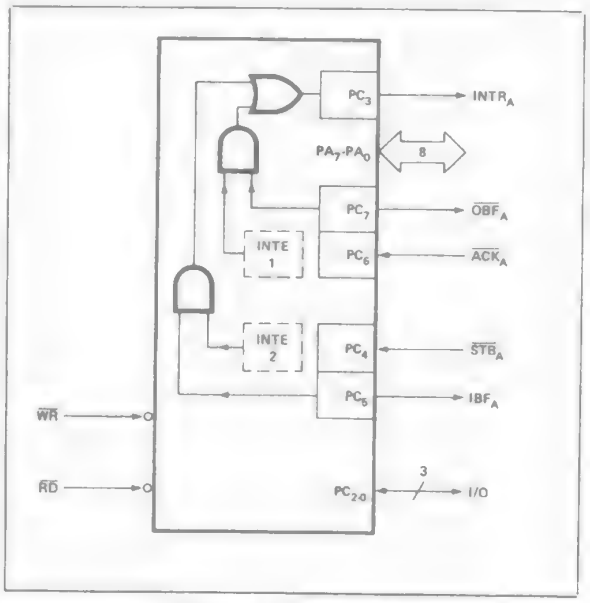


Figure 14. MODE 2

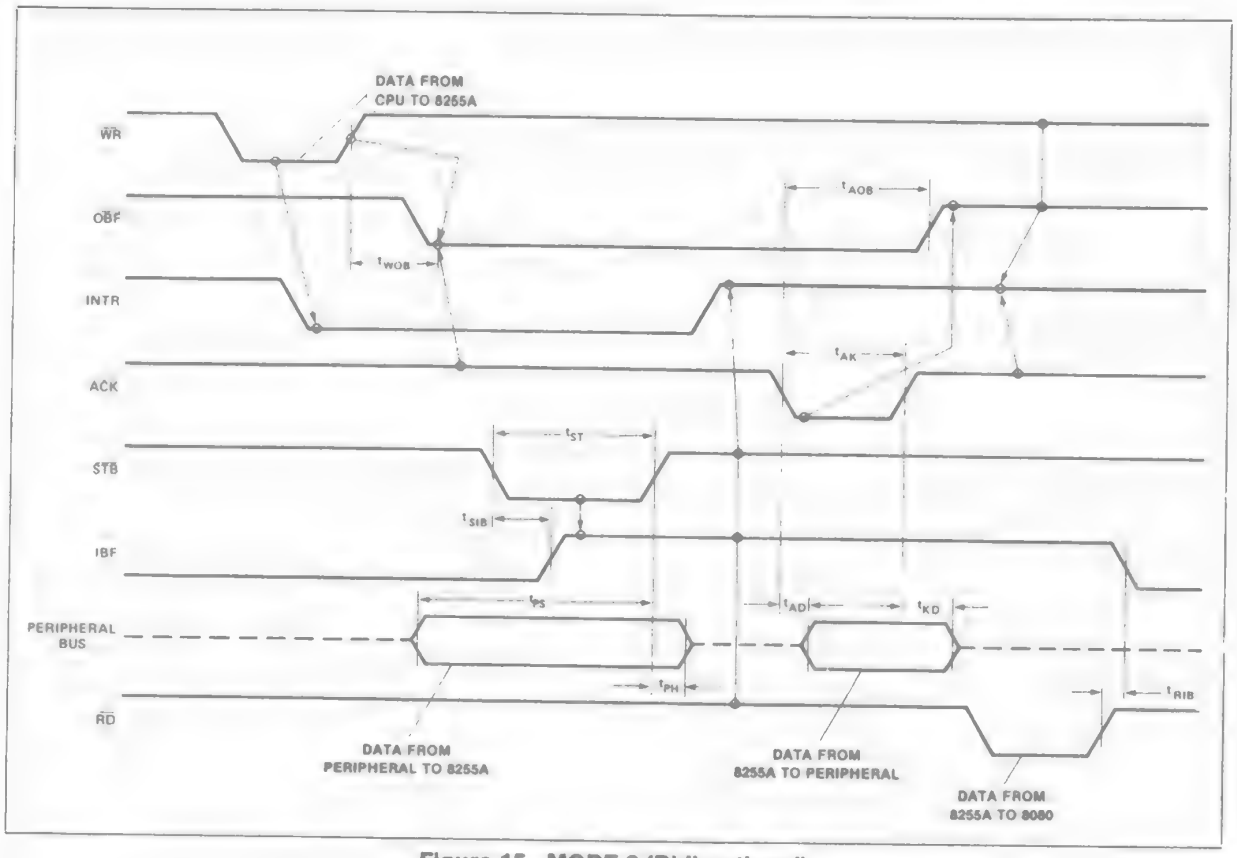


Figure 15. MODE 2 (Bidirectional)

NOTE: Any sequence where $\overline{WR}$ occurs before $\overline{ACK}$ and $\overline{STB}$ occurs before $\overline{RD}$ is permissible.
(INTR = IBF • $\overline{MASK}$ • $\overline{STB}$ • $\overline{RD}$ + $\overline{OBF}$ • $\overline{MASK}$ • $\overline{ACK}$ • $\overline{WR}$)

AFN-00744C

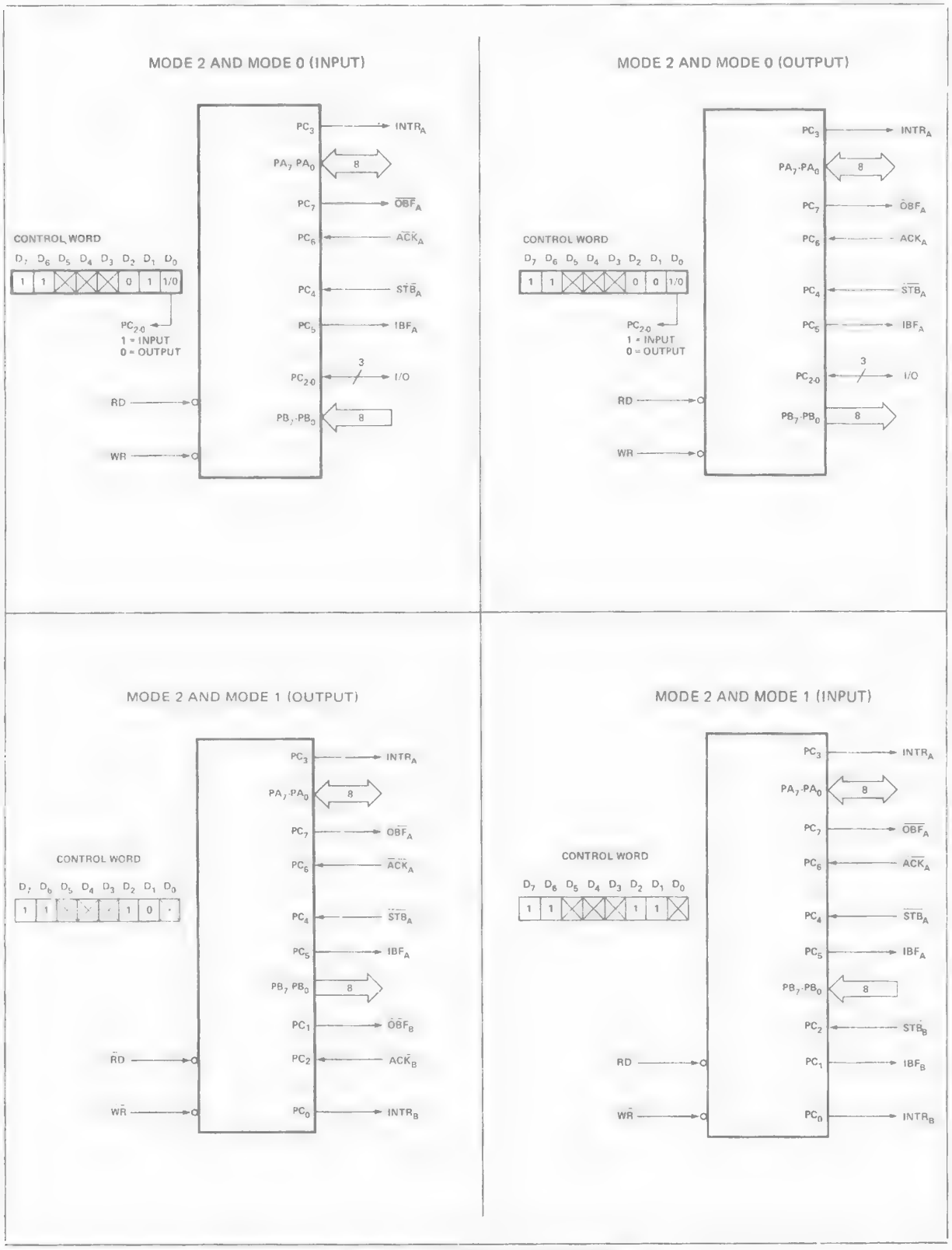


Figure 16. MODE ¼ Combinations

Mode Definition Summary

	MODE 0		MODE 1		MODE 2
	IN	OUT	IN	OUT	GROUP A ONLY
PA_0	IN	OUT	IN	OUT	↔
PA_1	IN	OUT	IN	OUT	↔
PA_2	IN	OUT	IN	OUT	↔
PA_3	IN	OUT	IN	OUT	↔
PA_4	IN	OUT	IN	OUT	↔
PA_5	IN	OUT	IN	OUT	↔
PA_6	IN	OUT	IN	OUT	↔
PA_7	IN	OUT	IN	OUT	↔
PB_0	IN	OUT	IN	OUT	—
PB_1	IN	OUT	IN	OUT	—
PB_2	IN	OUT	IN	OUT	—
PB_3	IN	OUT	IN	OUT	—
PB_4	IN	OUT	IN	OUT	—
PB_5	IN	OUT	IN	OUT	—
PB_6	IN	OUT	IN	OUT	—
PB_7	IN	OUT	IN	OUT	—
PC_0	IN	OUT	$INTR_B$	$INTR_B$	I/O
PC_1	IN	OUT	IBF_B	$\overline{OBF}_B$	I/O
PC_2	IN	OUT	$\overline{STB}_B$	$\overline{ACK}_B$	I/O
PC_3	IN	OUT	$INTR_A$	$INTR_A$	$INTR_A$
PC_4	IN	OUT	$\overline{STB}_A$	I/O	$\overline{STB}_A$
PC_5	IN	OUT	IBF_A	I/O	IBF_A
PC_6	IN	OUT	I/O	$\overline{ACK}_A$	$\overline{ACK}_A$
PC_7	IN	OUT	I/O	$\overline{OBF}_A$	$\overline{OBF}_A$

MODE 0 OR MODE 1 ONLY

Special Mode Combination Considerations

There are several combinations of modes when not all of the bits in Port C are used for control or status. The remaining bits can be used as follows:

If Programmed as Inputs –
All input lines can be accessed during a normal Port C read.

If Programmed as Outputs –
Bits in C upper (PC_7-PC_4) must be individually accessed using the bit set/reset function.

Bits in C lower (PC_3-PC_0) can be accessed using the bit set/reset function or accessed as a threesome by writing into Port C.

Source Current Capability on Port B and Port C

Any set of eight output buffers, selected randomly from Ports B and C can source 1mA at 1.5 volts. This feature allows the 8255 to directly drive Darlington type drivers and high-voltage displays that require such source current.

Reading Port C Status

In Mode 0, Port C transfers data to or from the peripheral device. When the 8255 is programmed to function in Modes 1 or 2, Port C generates or accepts "hand-shaking" signals with the peripheral device. Reading the contents of Port C allows the programmer to test or verify the "status" of each peripheral device and change the program flow accordingly.

There is no special instruction to read the status information from Port C. A normal read operation of Port C is executed to perform this function.

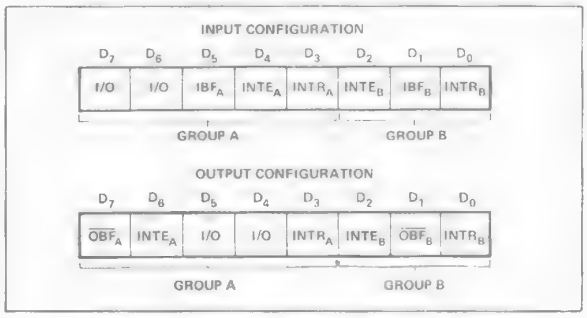


Figure 17. MODE 1 Status Word Format

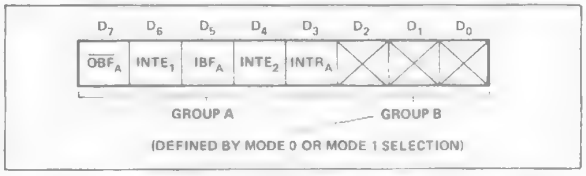


Figure 18. MODE 2 Status Word Format

APPLICATIONS OF THE 8255A

The 8255A is a very powerful tool for interfacing peripheral equipment to the microcomputer system. It represents the optimum use of available pins and is flexible enough to interface almost any I/O device without the need for additional external logic.

Each peripheral device in a microcomputer system usually has a "service routine" associated with it. The routine manages the software interface between the device and the CPU. The functional definition of the 8255A is programmed by the I/O service routine and becomes an extension of the system software. By examining the I/O devices interface characteristics for both data transfer and timing, and matching this information to the examples and tables in the detailed operational description, a control word can easily be developed to initialize the 8255A to exactly "fit" the application. Figures 19 through 25 present a few examples of typical applications of the 8255A.

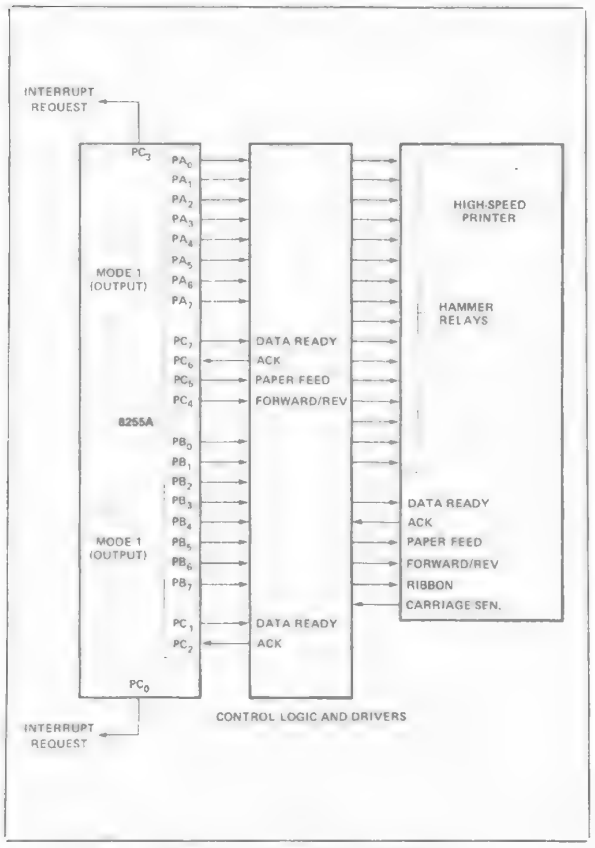


Figure 19. Printer Interface

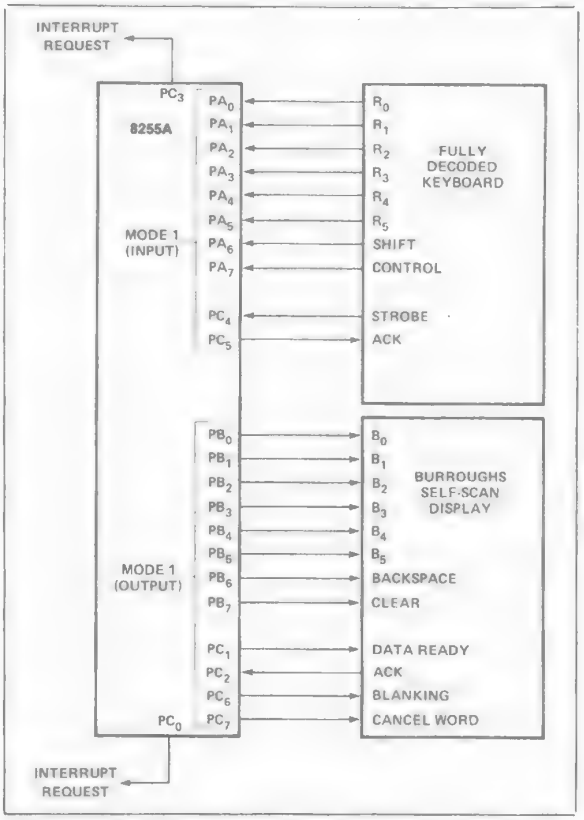


Figure 20. Keyboard and Display Interface

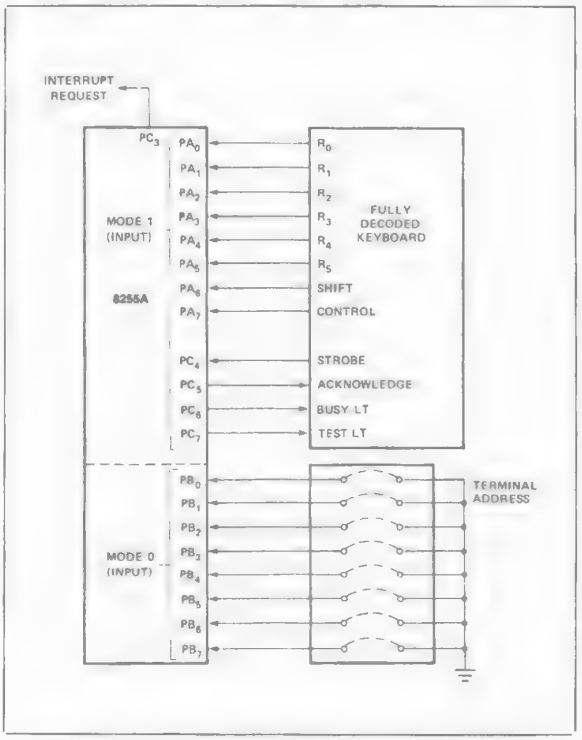


Figure 21. Keyboard and Terminal Address Interface

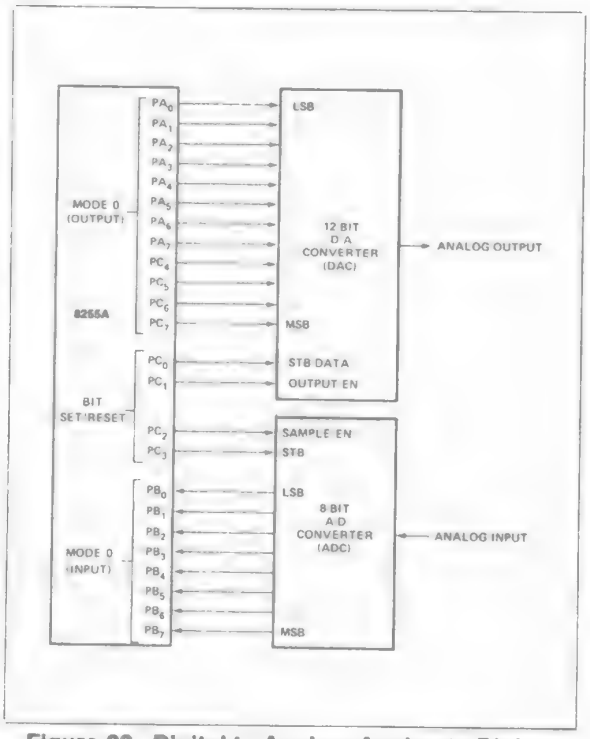


Figure 22. Digital to Analog, Analog to Digital

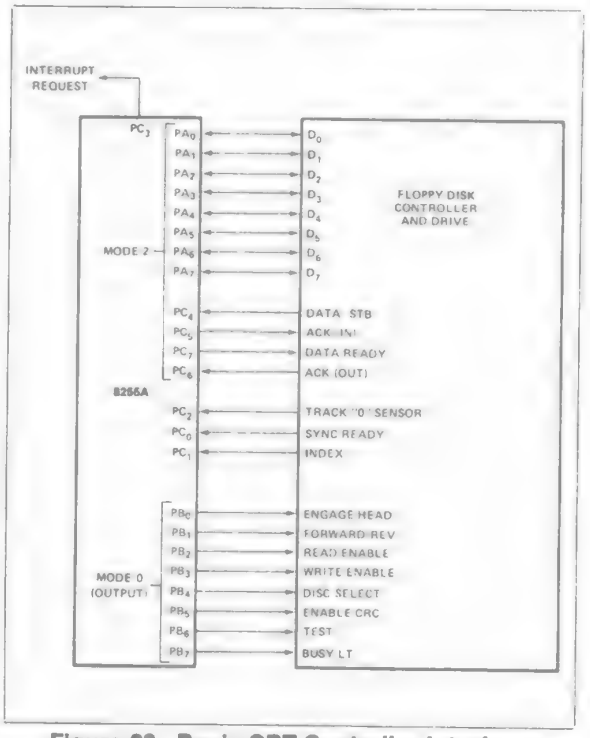


Figure 23. Basic CRT Controller Interface

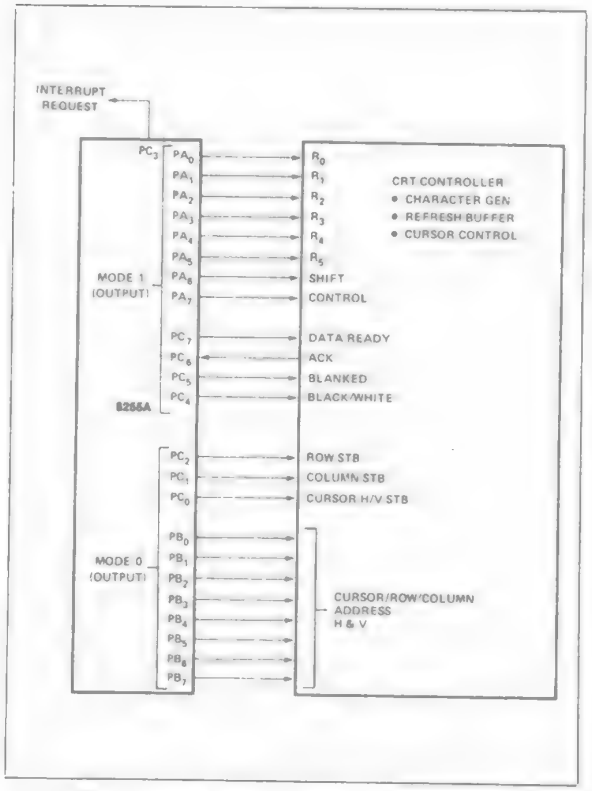


Figure 24. Basic Floppy Disc Interface

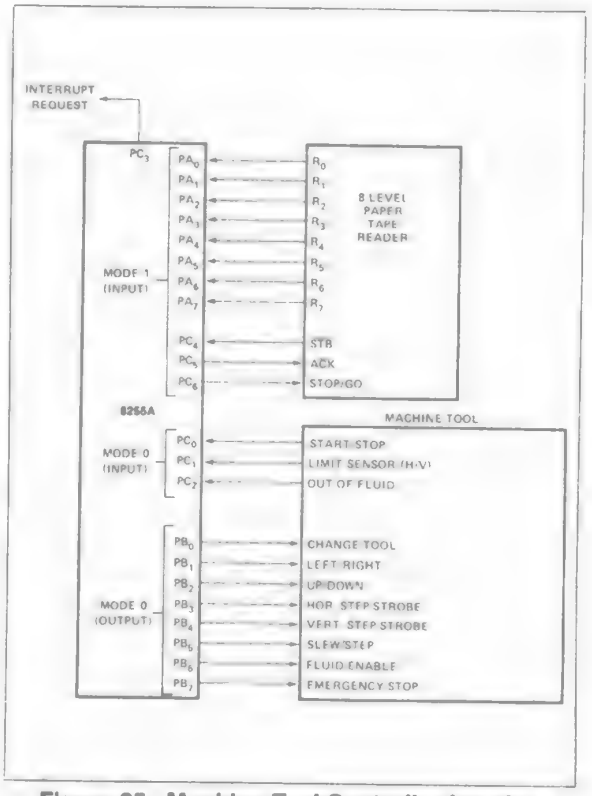


Figure 25. Machine Tool Controller Interface

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias. . . . . 0°C to 70°C
Storage Temperature . . . . . –65°C to +150°C
Voltage on Any Pin
With Respect to Ground . . . . . –0.5V to +7V
Power Dissipation . . . . . 1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = +5V ±10%, GND = 0V) *

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_{IL}	Input Low Voltage	-0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC}	V	
V_{OL} (DB)	Output Low Voltage (Data Bus)		0.45*	V	I_{OL} = 2.5mA
V_{OL}(PER)	Output Low Voltage (Peripheral Port)		0.45*	V	I_{OL} = 1.7mA
V_{OH}(DB)	Output High Voltage (Data Bus)	2.4		V	I_{OH} = -400μA
V_{OH}(PER)	Output High Voltage (Peripheral Port)	2.4		V	I_{OH} = -200μA
I_{DAR}[1]	Darlington Drive Current	-1.0	-4.0	mA	R_{EXT} = 750Ω; V_{EXT} = 1.5V
I_{CC}	Power Supply Current		120	mA	
I_{IL}	Input Load Current		±10	μA	V_{IN} = V_{CC} to 0V
I_{OFL}	Output Float Leakage		±10	μA	V_{OUT} = V_{CC} to .45V

NOTE:
1. Available on any 8 pins from Port B and C.

CAPACITANCE (T_A = 25°C, V_{CC} = GND = 0V)

Symbol	Parameter	Min.	Typ.	Max.	Unit	Test Conditions
C_{IN}	Input Capacitance			10	pF	fc = 1MHz
$C_{I/O}$	I/O Capacitance			20	pF	Unmeasured pins returned to GND

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = +5V ±10%, GND = 0V) *

Bus Parameters

READ

Symbol	Parameter	8255A		8255A-5		Unit
		Min.	Max.	Min.	Max.	
t_{AR}	Address Stable Before READ	0		0		ns
t_{RA}	Address Stable After READ	0		0		ns
t_{RR}	READ Pulse Width	300		300		ns
t_{RD}	Data Valid From READ[1]		250		200	ns
t_{DF}	Data Float After READ	10	150	10	100	ns
t_{RV}	Time Between READs and/or WRITEs	850		850		ns

A.C. CHARACTERISTICS (Continued)

WRITE

Symbol	Parameter	8255A Min.	8255A Max.	8255A-5 Min.	8255A-5 Max.	Unit
t_{AW}	Address Stable Before WRITE	0		0		ns
t_{WA}	Address Stable After WRITE	20		20		ns
t_{WW}	WRITE Pulse Width	400		300		ns
t_{DW}	Data Valid to WRITE (T.E.)	100		100		ns
t_{WD}	Data Valid After WRITE	30		30		ns

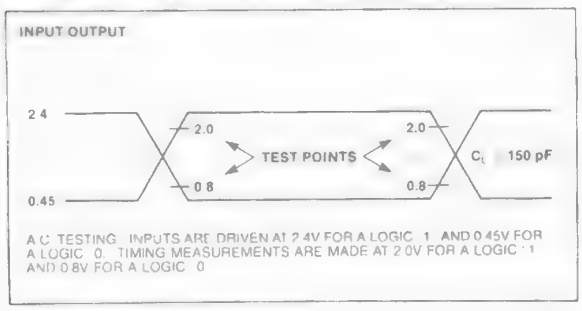
OTHER TIMINGS

Symbol	Parameter	8255A Min.	8255A Max.	8255A-5 Min.	8255A-5 Max.	Unit
t_{WB}	WR = 1 to Output[1]		350		350	ns
t_{IR}	Peripheral Data Before RD	0		0		ns
t_{HR}	Peripheral Data After RD	0		0		ns
t_{AK}	ACK Pulse Width	300		300		ns
t_{ST}	STB Pulse Width	500		500		ns
t_{PS}	Per. Data Before T.E. of STB	0		0		ns
t_{PH}	Per. Data After T.E. of STB	180		180		ns
t_{AD}	ACK = 0 to Output[1]		300		300	ns
t_{KD}	ACK = 1 to Output Float	20	250	20	250	ns
t_{WOB}	WR = 1 to OBF = 0[1]		650		650	ns
t_{AOB}	ACK = 0 to OBF = 1[1]		350		350	ns
t_{SIB}	STB = 0 to IBF = 1[1]		300		300	ns
t_{RIB}	RD = 1 to IBF = 0[1]		300		300	ns
t_{RIT}	RD = 0 to INTR = 0[1]		400		400	ns
t_{SIT}	STB = 1 to INTR = 1[1]		300		300	ns
t_{AIT}	ACK = 1 to INTR = 1[1]		350		350	ns
t_{WIT}	WR = 0 to INTR = 0[1,3]		450		450	ns

NOTES:
1. Test Conditions: C_L = 150 pF.
2. Period of Reset pulse must be at least 50μs during or after power on. Subsequent Reset pulse can be 500 ns min.
3. INTR↑ may occur as early as $\overline{WR}$↓.

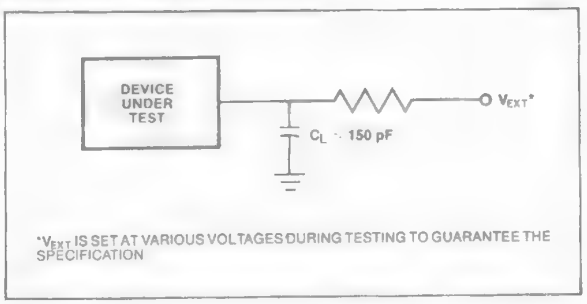
* For Extended Temperature EXPRESS, use M8255A electrical parameters.

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING: INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0". TIMING MEASUREMENTS ARE MADE AT 2.0V FOR A LOGIC "1" AND 0.8V FOR A LOGIC "0".

A.C. TESTING LOAD CIRCUIT



*V_{EXT} IS SET AT VARIOUS VOLTAGES DURING TESTING TO GUARANTEE THE SPECIFICATION

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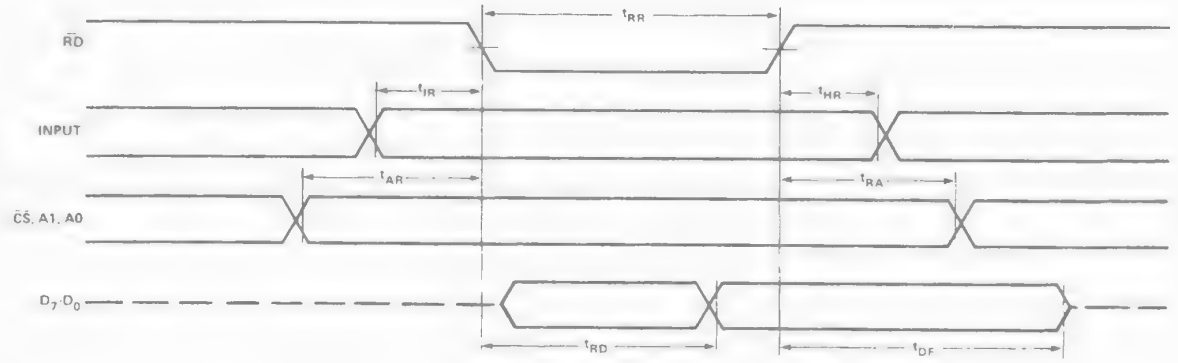
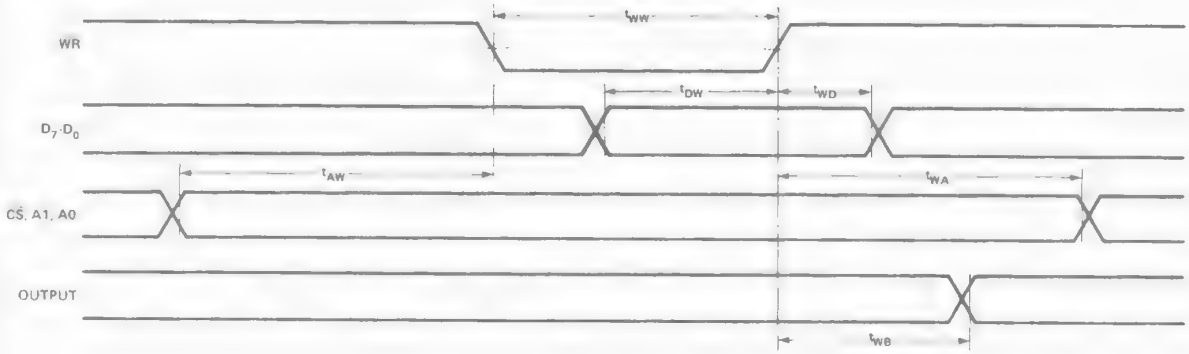
WAVEFORMS

MODE 0 (BASIC INPUT)

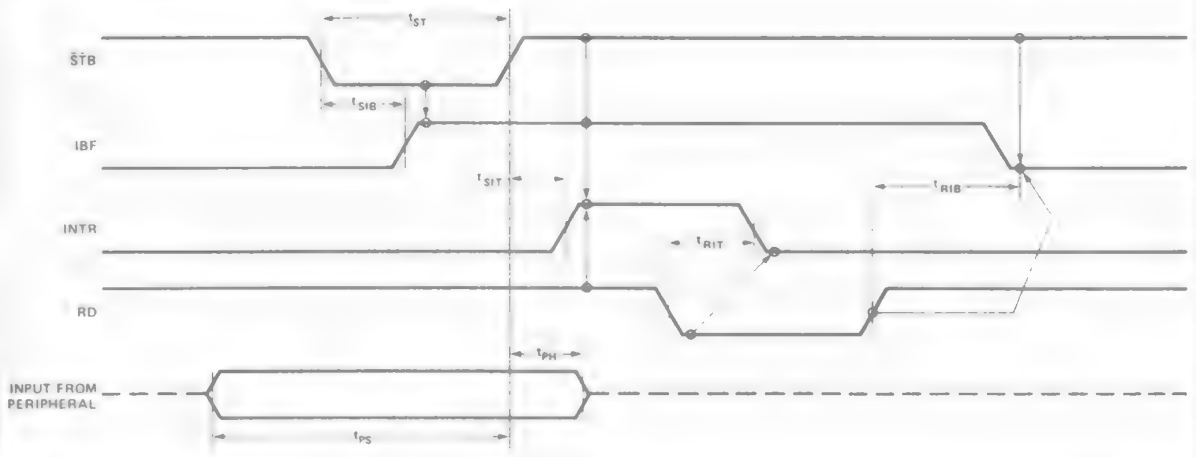


MODE 0 (BASIC OUTPUT)

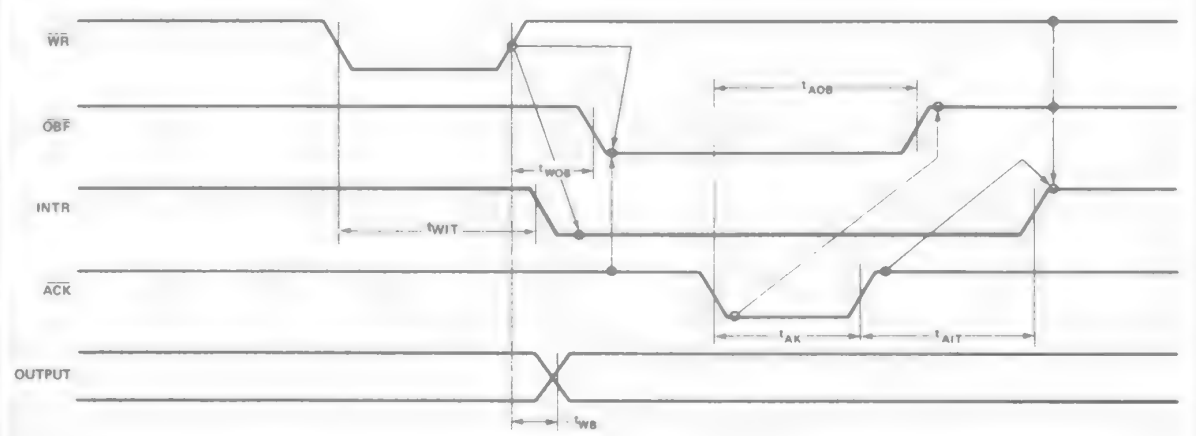


WAVEFORMS (Continued)

MODE 1 (STROBED INPUT)

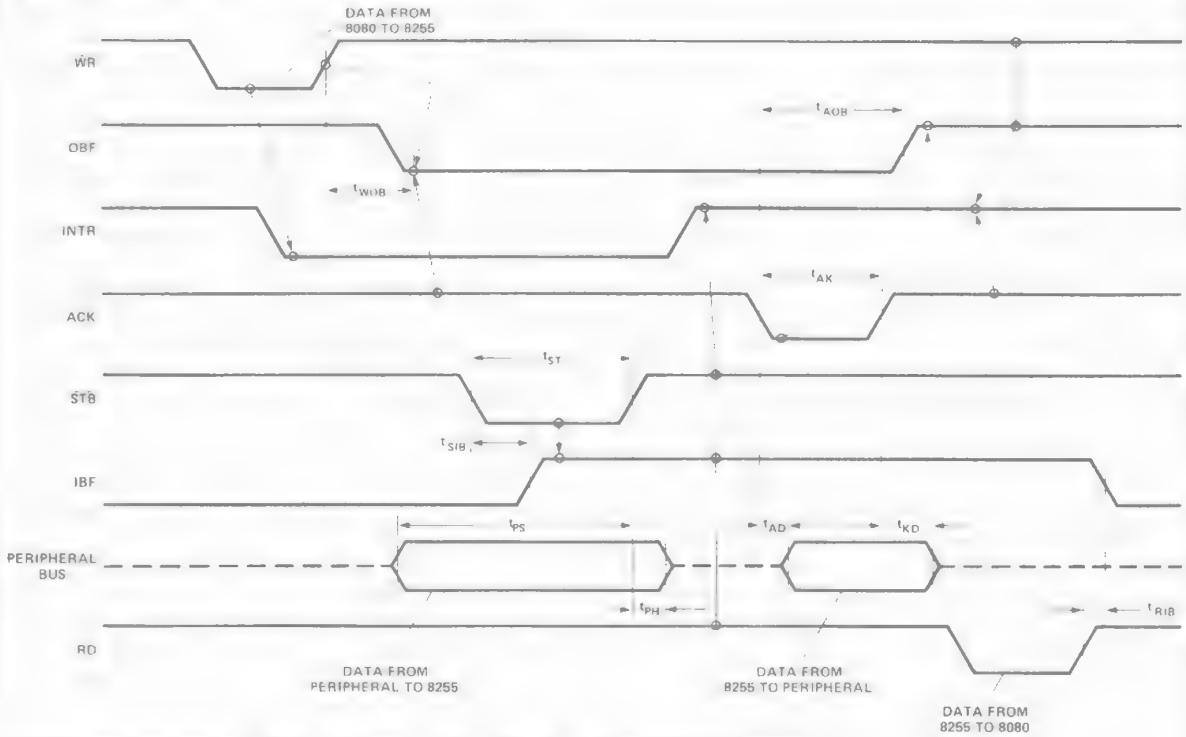


MODE 1 (STROBED OUTPUT)



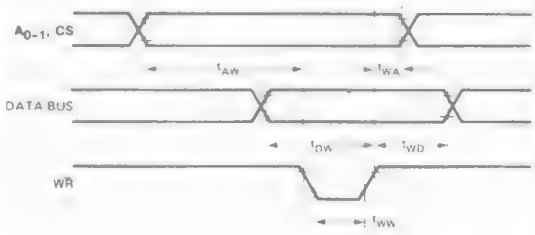
WAVEFORMS (Continued)

MODE 2 (BIDIRECTIONAL)

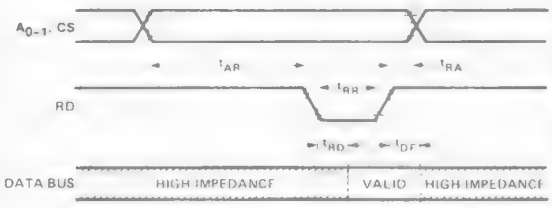


NOTE: Any sequence where $\overline{WR}$ occurs before $\overline{ACK}$ and $\overline{STB}$ occurs before $\overline{RD}$ is permissible.
($INTR = IBF \cdot \overline{MASK} \cdot \overline{STB} \cdot \overline{RD} + \overline{OBF} \cdot \overline{MASK} \cdot \overline{ACK} \cdot \overline{WR}$)

WRITE TIMING



READ TIMING



ADVANCE INFORMATION

8256
MULTIFUNCTION UNIVERSAL ASYNCHRONOUS RECEIVER-TRANSMITTER (MUART)

- **Programmable Serial Asynchronous Communications Interface for 5-, 6-, 7-, or 8-Bit Characters, 1, 1½, or 2 Stop Bits, and Parity Generation**
- **On-Board Baud Rate Generator Programmable for 13 Common Baud Rates up to 19.2K Bits/second, or an External Baud Clock Maximum of 1M Bit/second**
- **Five 8-Bit Programmable Timer/Counters; Four Can Be Cascaded to Two 16-Bit Timer/Counters**
- **Two 8-Bit Programmable Parallel I/O Ports; Port 1 Can Be Programmed for Port 2 Handshake Controls and Event Counter Inputs**
- **Eight-Level Priority Interrupt Controller Programmable for 8085 or iAPX 86, iAPX 88 Systems and for Fully Nested Interrupt Capability**
- **Programmable System Clock to 1 ×, 2 ×, 3 ×, or 5 × 1.024 MHz**

The Intel® 8256 Multifunction Universal Asynchronous Receiver-Transmitter (MUART) combines five commonly used functions into a single 40-pin device. It is designed to interface to the 8048, 8085A, iAPX 86, and iAPX 88 to perform serial communications, parallel I/O, timing, event counting, and priority interrupt functions. All of these functions are fully programmable through nine internal registers. In addition, the five timer/counters and two parallel I/O ports can be accessed directly by the microprocessor.

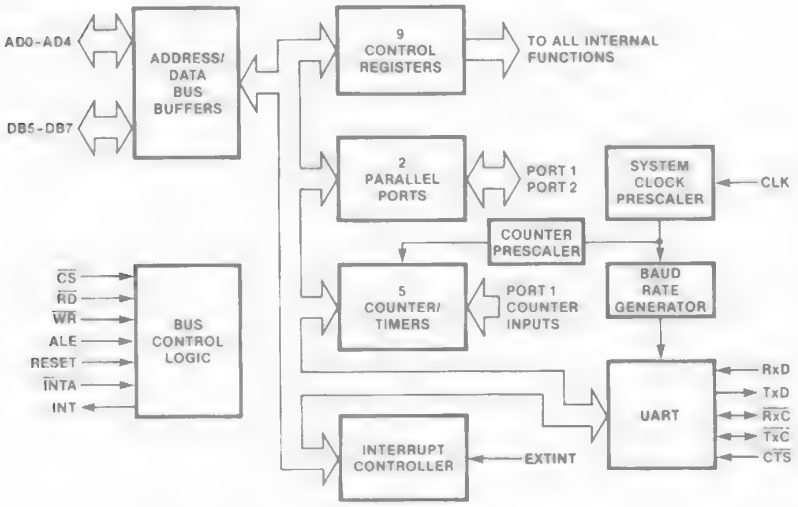


Figure 1. MUART Block Diagram

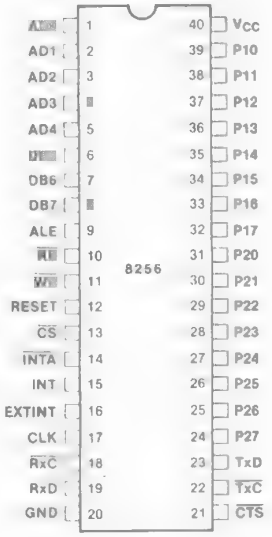


Figure 2. MUART Pin Configuration

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
AD0-AD4 DB5-DB7	1-5 6-8	I/O	**Address/Data:** Three-State Address/Data lines which interface with the CPU lower 8-bit address/data bus. The 5-bit address is latched on the falling edge of ALE. In 8048 and 8085 mode, AD0-AD3 are used to select the proper register, while AD1-AD4 are used in 8086 and 8088 mode. The 8-bit bidirectional data bus is either written into or read from the chip depending on the latched $\overline{CS}$ and $\overline{RD}$ or $\overline{WR}$.
ALE	9	I	**Address Latch Enable:** Latches the 5 address lines on AD0-AD4 and $\overline{CS}$ on the falling edge.
$\overline{RD}$	10	I	**Read Control:** When this signal is low, the previously selected register is enabled onto the data bus.
$\overline{WR}$	11	I	**Write Control:** When this signal is low, the value on the data bus is placed into the previously selected register.
RESET	12	I	Pulse provided by the CPU to initialize the system. The MUART remains "idle" until it is reprogrammed by the CPU.
$\overline{CS}$	13	I	**Chip Select:** A low on this signal enables the MUART. It is latched with the address on the falling edge of ALE, and $\overline{RD}$ and $\overline{WR}$ have no effect unless $\overline{CS}$ was latched low during the ALE cycle.
$\overline{INTA}$	14	I	**Interrupt Acknowledge:** If the MUART has been enabled to respond to interrupts, it puts an RST on the bus for the 8085 or a vector for the 8086. The bit in the interrupt register is reset when the interrupt is placed onto the bus.
INT	15	O	**Interrupt:** A high signals the CPU that the MUART needs service.
EXTINT	16	I	**External Interrupt:** A high on this pin signals that an external device requests service. EXTINT must be held high until $\overline{INTA}$ or read interrupt occurs.
CLK	17	I	**System Clock:** This input provides an accurate timing source for the MUART. It must be 1×, 2×, 3×, or 5× 1.024 MHz and is used by the baud rate generator and real time clocks.
$\overline{RxC}$	18	I/O	**Receive Clock:** If baud rate 0 is selected, this input clocks bits into RxD on the rising edge. If a baud rate from $1\text{-}0F_{16}$ is selected, this output will provide a rising edge at the center of each received data bit. This output remains high during start, stop, and parity bits.
RxD	19	I	**Receive Data:** Serial data input from the modem or terminal to the MUART.
GND		PS	**Ground:** Power supply and logic ground reference.
V_{CC}	40	PS	**Power:** +5V POWER supply.
P17-P10	32-39	I/O	**Parallel I/O Port 1:** Each pin can be programmed as an input or an output to perform general purpose I/O functions for the CPU under software control. In addition to general I/O, I/O Port 1 can be programmed to a variety of special functions for handshake control, counter inputs, and special communications functions.
P27-P20	24-31	I/O	**Parallel I/O Port 2:** Each nibble (4 bits) of this port can be either an input or an output. Also, this port can be used as a bidirectional 8-bit port using handshake lines in Port 1.
TxD	23	O	**Transmit Data:** This output carries the serial data to the terminal or modem from the MUART.
$\overline{TxC}$	22	I/O	**Transmit Clock:** If the baud rate is 0, this input clocks data out of the transmitter on the falling edge. If a baud rate of 1 or 2 is selected, this input permits the user to provide a 32× or 64× clock which is used for the receiver and transmitter. If the baud rate is $3\text{-}0F_{16}$, the internal transmitter clock is output. If 1½ stop bits are selected and characters are continuously transmitted, the internal baud rate generator will be reset at the end of the stop bits and the clock will have a small positive spike instead of a half clock. A high-to-low transition occurs at the beginning of each bit and a low-to-high transition at the center of each bit.
$\overline{CTS}$	21	I	**Clear to Send:** This input enables the serial transmitter. If $\overline{CTS}$ is low, any character in the transmitter buffer will be sent. A single negative-going pulse causes the transmission of a single previously loaded character out of the transmitter buffer. If this pulse occurs when the buffer is empty or during the transmission of a character up to 0.5 of the first stop bit, it will be ignored. If a baud rate from $1\text{-}0F_{16}$ is selected, $\overline{CTS}$ must be low for at least 1/32 of a bit, or it will be ignored.

FUNCTIONAL DESCRIPTION

The 8256 Multi-Function Universal Asynchronous Receiver-Transmitter (MUART) combines five commonly used functions onto a single 40-pin device. The MUART performs asynchronous serial communications, parallel I/O, timing, event counting, and interrupt control.

Serial Communications

The serial communications portion of the MUART contains a full-duplex asynchronous receiver-transmitter (UART). A programmable baud rate generator is included on the MUART to permit a variety of operating speeds without external components. The UART can be programmed by the CPU for a variety of character sizes, parity generation and detection, error detection, and start/stop bit handling. The receiver checks the start and stop bits in the center of the bit, and a break halts the reception of data. The transmitter can send breaks and can be controlled by an external enable pin.

Parallel I/O

The MUART includes 16 bits of general purpose parallel I/O. Eight bits (Port 1) can be individually changed from input to output or used for special I/O functions. The other eight bits (Port 2) can be used as nibbles (4 bits) or as bytes. These eight bits also include a handshaking capability using two pins on Port 1.

Counter/Timers

There are five 8-bit counter/timers on the MUART. The timers can be programmed to use either a 1 kHz or 16 kHz clock generated from the system clock. Four of the 8-bit counter/timers can be cascaded to two 16-bit counter/timers, and one of the 8-bit counter/timers can be reset to its initial value by an external signal.

Interrupts

An eight-level priority interrupt controller can be configured for fully nested or normal interrupt priority. Seven of the eight interrupts service functions on the MUART (counter/timers, UART), and one external interrupt is provided which can be used for a particular function or for chaining interrupt controllers or more MUARTs. The MUART will support 8085 and 8086/88 systems with direct interrupt vectoring, or the MUART can be polled to determine the cause of the interrupt.

Command Register 1

L1	L0	S1	S0	BRKI	BITI	8086	FRQ
	(0R)				(0W)		

FRQ — Timer Frequency Select

This bit selects between two frequencies for the five timers. If FRQ = 0, the timer input frequency is 16 kHz (62.5 μs). If FRQ = 1, the timer input frequency is 1 kHz (1 ms). The selected clock frequency is shared by all the counter/timers enabled for timing; thus, all timers must run with the same time base.

8086 — 8086 Mode Enable

This bit selects between 8048/8085 mode and 8086/8088 mode. In 8085 mode (8086 = 0), A0 to A3 are used to address the internal registers, and an RST instruction is generated in response to the first $\overline{INTA}$. In 8086 mode (8086 = 1), A1 to A4 are used to address the internal registers, and A0 is used as an extra chip select (A0 must equal zero to be enabled). The response to $\overline{INTA}$ is for 8086 interrupts where the first $\overline{INTA}$ is ignored, and an interrupt vector (40_{16} to 47_{16}) is placed on the bus in response to the second $\overline{INTA}$.

BITI — Interrupt on Bit Change

This bit disables the Timer 2 interrupt and enables an interrupt when a low-to-high transition occurs on pin 7 of Port 1 (pin 32).

BRKI — Break-In Detect Enable

This bit enables the break-in detect feature. A break-in is detected when pin 6 of Port 1 (pin 33) is low during the first stop bit of a transmitted character. This could be used to detect a break-in condition by connecting the serial transmission line to pin 33. A break-in detect is OR-ed with break detect in bit 3 of the Status Register. If $\overline{RxC}$ and $\overline{TxC}$ are used for the serial bit rates, break-in cannot be detected.

S0, S1 — Stop Bit Length

S1	S0	Stop Bit Length
0	0	1
0	1	1.5
1	0	2
1	1	0.75

If 0.75 stop bits is selected, $\overline{CTS}$ becomes edge sensitive rather than level sensitive. A high-to-low transition of $\overline{CTS}$ *immediately* initiates the transmission of the next character. A high-to-low transition will be ignored if the transmit buffer is empty, or if it occurs before 0.75 of the first stop bit. It will shorten the stop

Table 2. MUART Registers

Read Registers								8085 Mode: AD3 / 8086 Mode: AD4	AD2 / AD3	AD1 / AD2	AD0 / AD1	Write Registers							
L1	L0	S1	S0	BRKI	BITI	8086	FRQ	0	0	0	0	L1	L0	S1	S0	BRKI	BITI	[illegible]	FRQ
Command 1												Command 1							
PEN	EP	C1	C0	B3	B2	B1	B0	0	0	0	1	PEN	EP	C1	C0	B3	B2	B1	B0
Command 2												Command 2							
0	RxE	IAE	NIE	0	SBRK	TBRK	0	0	0	1	0	SET	RxE	IAE	NIE	END	SBRK	TBRK	RST
Command 3												Command 3							
T35	T24	T5C	CT3	CT2	P2C2	P2C1	P2C0	0	0	1	1	T35	T24	T5C	CT3	CT2	P2C2	P2C1	P2C0
Mode												Mode							
P17	P16	P15	P14	P13	P12	P11	P10	0	1	0	0	P17	P16	P15	P14	P13	P12	P11	P10
Port 1 Control												Port 1 Control							
L7	L6	L5	L4	L3	L2	L1	L0	0	1	0	1	L7	L6	L5	L4	L3	L2	L1	L0
Interrupt Enable												Set Interrupts							
D7	D6	D5	D4	D3	D2	D1	D0	0	1	1	0	L7	L6	L5	L4	L3	L2	L1	L0
Interrupt Address												Reset Interrupts							
D7	D6	D5	D4	D3	D2	D1	D0	0	1	1	1	D7	D6	D5	D4	D3	D2	D1	D0
Receiver Buffer												Transmitter Buffer							
D7	D6	D5	D4	D3	D2	D1	D0	1	0	0	0	D7	D6	D5	D4	D3	D2	D1	D0
Port 1												Port 1							
D7	D6	D5	D4	D3	D2	D1	D0	1	0	0	1	D7	D6	D5	D4	D3	D2	D1	D0
Port 2												Port 2							
D7	D6	D5	D4	D3	D2	D1	D0	1	0	1	0	D7	D6	D5	D4	D3	D2	D1	D0
Timer 1												Timer 1							
D7	D6	D5	D4	D3	D2	D1	D0	1	0	1	1	D7	D6	D5	D4	D3	D2	D1	D0
Timer 2												Timer 2							
D7	D6	D5	D4	D3	D2	D1	D0	1	1	0	0	D7	D6	D5	D4	D3	D2	D1	D0
Timer 3												Timer 3							
D7	D6	D5	D4	D3	D2	D1	D0	1	1	0	1	D7	D6	D5	D4	D3	D2	D1	D0
Timer 4												Timer 4							
D7	D6	D5	D4	D3	D2	D1	D0	1	1	1	0	D7	D6	D5	D4	D3	D2	D1	D0
Timer 5												Timer 5							
INT	RBF	TBE	TRE	BD	PE	OE	FE	1	1	1	1	0	RS4	RS3	RS2	RS1	RS0	TME	DSC
Status												Modification							

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bit if it occurs after ¾ of the stop bit has been sent. If $\overline{CTS}$ is high or low or a low-to-high transition occurs, the transmitter remains idle.

L0, L1 — Character Length

L1	L0	Character Length
0	0	8
0	1	7
1	0	6
1	1	5

Command Register 2

PEN	EP	C1	C0	B3	B2	B1	B0
	(1R)				(1W)		

B0, B1, B2, B3 — Baud Rate Select

B3	B2	B1	B0	Baud Rate	Sampling Rate
0	0	0	0	$\overline{TxC}$, $\overline{RxC}$	1
0	0	0	1	$\overline{TxC}$/64	64
0	0	1	0	$\overline{TxC}$/32	32
0	0	1	1	19200	32
0	1	0	0	9600	64
0	1	0	1	4800	64
0	1	1	0	2400	64
0	1	1	1	1200	64
1	0	0	0	600	64
1	0	0	1	300	64
1	0	1	0	200	64
1	0	1	1	150	64
1	1	0	0	110	64
1	1	0	1	100	64
1	1	1	0	75	64
1	1	1	1	50	64

If the baud rate is 0, then both the transmitter and receiver operate from separate external clocks. If the baud rate is 1 or 2, then both the transmitter and receiver divide the $\overline{TxC}$ by 64 or 32, respectively.

C0, C1 — System Clock Divider

C1	C0	Divider Ratio	System Clock Frequency
0	0	5	5.120 MHz
0	1	3	3.072 MHz
1	0	2	2.048 MHz
1	1	1	1.024 MHz

EP — Even Parity

If parity is enabled, then even parity is enabled by a 1 and odd parity is enabled by a 0.

PEN — Parity Enable

This enables parity detection and generation. The type of parity is determined by the EP bit.

Command Register 3

SET	RxE	IAE	NIE	END	SBRK	TBRK	RST
	(2R)				(2W)		

Command Register 3 is different from the first two registers because it has a bit set/reset capability. Writing a byte with bit 7 high sets any bits which were also high. Writing a byte with bit 7 low resets any bits which were high. If any bit 0–6 is low, no change occurs to that bit. When Command Register 3 is read, bits 0, 3, and 7 will always be zero.

RST — Reset

If RST is set, the following events occur:

1. All bits in the Status Register except bits 4 and 5 are cleared, and bits 4 and 5 are set.
2. The Interrupt Enable, Interrupt Request, and Interrupt Service Registers are cleared.
3. The receiver and transmitter are reset. The transmitter goes idle (TxD is high), and the receiver enters start bit search mode.
4. If Port 2 is programmed for handshake mode, $\overline{IBF}$ and $\overline{OBF}$ are reset high.

RST does *not* alter ports, data registers or command registers, but it halts any operation in progress. RST is automatically cleared.

TBRK — Transmit Break

This causes the transmitter data to be set low, and it stays low until TBRK is cleared. As long as break is active, data transfer from the Transmitter Buffer to the Transmitter Register will be inhibited.

SBRK — Single Character Break

This causes the transmitter data to be set low for one character including start bit, data bits, parity bit, and stop bits. SBRK is automatically cleared when time for the last data bit has passed. It will start after the character in progress completes and will delay the next data transfer from the Transmitter Buffer to the Transmitter Register until TxD returns to an idle (marking) state. If both TBRK and SBRK are set, break will be sent as long as TBRK is set, but SBRK will be cleared after one character time of break. If SBRK is set again, it remains set for another character. The user can send a definite number of break characters in this manner by clearing TBRK after setting SBRK for the last character time.

END — End of Interrupt

If fully nested interrupt mode is selected, this bit resets the currently served interrupt level in the Interrupt Service Register. *This command must occur at the end of each interrupt service routine during fully nested*

interrupt mode. END is automatically cleared when the Interrupt Service Register (internal) is cleared. See the NIE description for more information on nested interrupt servicing. END is ignored if nested interrupts are not enabled.

NIE — Nested Interrupt Enable

This bit enables fully nested interrupts. In this mode, the service routine for a lower priority interrupt can be interrupted by a request from a higher priority task.

In fully nested interrupt mode, $\overline{\text{INTA}}$ or reading the Interrupt Address Register resets the highest priority interrupt bit in the Interrupt Register (internal), sets the corresponding bit in the Interrupt Service Register (internal), and resets INT. If an interrupt of higher priority than the currently served interrupt is requested or the END bit is set while another interrupt request is pending, the INT line will go high again. If an interrupt service routine is interrupted by an interrupt of higher priority, two or more bits in the Interrupt Service Register will be set.

If NIE is low, interrupt priority is used only when two interrupts occur at the same time. INT will be high as long as the CPU has not responded to all the interrupts in the Interrupt Register.

IAE — Interrupt Acknowledge Enable

This bit enables an automatic response to $\overline{\text{INTA}}$. The particular response is determined by the 8086 bit in Command Register 1.

RxE — Receiver Enable

This bit enables the serial receiver. The Receiver Buffer and all receiver status information will be disabled except for the break detect status.

SET — Bit Set/Reset

If this bit is high during a write to Command Register 3, then any bit marked by a high will be set. If this bit is low, then any bit marked by a high will be cleared.

Mode Register

T35	T24	T5C	CT3	CT2	P2C2	P2C1	P2C0
	(3R)				(3W)		

P2C2, P2C1, P2C0 — Port 2 Control

P2C2	P2C1	P2C0	Mode	Direction Upper	Direction Lower
0	0	0	nibble	input	input
0	0	1	nibble	input	output
0	1	0	nibble	output	input
0	1	1	nibble	output	output
1	0	0	byte handshake	input	
1	0	1	byte handshake	output	
1	1	0	*DO NOT USE*		
1	1	1	test		

If test mode is selected and BRG of Port 1 Control Register is set, then the output from the internal baud rate generator is placed on pin 4 of Port 1 (pin 35).

CT2, CT3 — Counter/Timer Mode

If CT2 or CT3 are high, then counter/timer 2 or 3 respectively is configured as an event counter on pin 2 or 3 respectively of Port 1 (pins 37 or 36). The event counter decrements the count by one on each low-to-high transition of the external input. If CT2 or CT3 is low, then the respective counter/timer is configured as a timer and the Port 1 pins are used for parallel I/O.

T5C — Timer 5 Control

If T5C is set, then Timer 5 can be preset and started by an external signal. Writing to the Timer 5 Register loads the Timer 5 Save Register and stops the timer. A high-to-low transition on pin 5 of Port 1 (pin 34) loads the timer with the saved value and starts the timer. The next high-to-low transition on pin 5 retriggers the timer by reloading it with the initial value and continues timing.

When the timer reaches zero it issues an interrupt request, disables its interrupt level and continues counting. A subsequent high-to-low transition on pin 5 resets Timer 5 to its initial value. For another timer interrupt, the Timer 5 interrupt enable bit must be set again.

T35, T24 — Cascade Timers

These two bits cascade Timers 3 and 5 or 2 and 4. Timers 2 and 3 are the lower bytes, while Timers 4 and 5 are the upper bytes. If T5C is set, then both Timers 3 and 5 can be preset and started by an external pulse. When a high-to-low transition occurs, Timer 5 is preset to its saved value, but Timer 3 is always preset to all ones. If either CT2 or CT3 is set, then the corresponding timer pair is a 16-bit event counter.

Port 1 Control Register

P17	P16	P15	P14	P13	P12	P11	P10
	(4R)				(4W)		

Each bit in the Port 1 Control Register configures the direction of the corresponding pin. If the bit is high, the pin is an output, and if it is low the pin is an input. Every Port 1 pin has another function which is controlled by other registers. If that special function is disabled, the pin functions as a general I/O pin as specified by this register. The special functions for each pin are described below.

Port 10, 11 — Handshake Control

If byte handshake control is enabled for Port 2 by the Mode Register, then Port 10 is programmed as $\overline{\text{STB}}$/$\overline{\text{ACK}}$ handshake control input and Port 11 is programmed as $\overline{\text{IBF}}$/$\overline{\text{OBF}}$ handshake control output.

If byte handshake mode is enabled for output on Port 2, $\overline{\text{OBF}}$ indicates that a character has been loaded into the

Port 2 output buffer. When an external device reads the data, it acknowledges this operation by driving $\overline{ACK}$ low. $\overline{OBF}$ is set low by writing to Port 2 and is reset high by $\overline{ACK}$.

If byte handshake mode is enabled for input on Port 2, $\overline{STB}$ is an input to the MUART to latch the data into Port 2. After the data is latched, $\overline{IBF}$ is driven low. $\overline{IBF}$ is reset high when Port 2 is read.

Port 12, 13 — Counter 2, 3 Input

If Timer 2 or Timer 3 is programmed as an event counter by the mode register, then Port 12 or 13 is the counter input for Event Counter 2 or 3, respectively.

Port 14 — Baud Rate Generator Output Clock

If test mode is enabled by the Mode Register and Command Register 2 baud rate select is greater than 2, then Port 14 is an output from the internal baud rate generator.

Port 15 — Timer 5 Trigger

If T5C is set in the Mode Register enabling a re-triggerable timer, then Port 15 is the input which starts and reloads Timer 5.

Port 16 — Break-in Detect

If break-in detect is enabled by BRKI in Command Register 1, then this input is used to sense a break-in. If Port 16 is low while the serial transmitter is sending the last stop bit, then a break-in condition is signaled.

Port 17 — Port Interrupt Source

If BITI in Command Register 1 is set, then a low-to-high transition on Port 17 generates an interrupt request on priority level 1.

Receiver and Transmitter Buffer

D7	D6	D5	D4	D3	D2	D1	D0
(7R)					(7W)		

Both the transmitter and the receiver in the MUART are fully double buffered. The Receiver Buffer full flag is cleared when the character is read. If the character is not read before the next character's first stop bit, then an overrun error is generated. Bytes written to the Transmitter Buffer are held until the Transmitter Register (internal) is empty. If the Transmitter Register is empty, the byte is transferred immediately and the Transmitter Buffer empty flag is set. If a serial character length is less than 8 bits, then the unused most significant bits are set to zero on a read and are ignored on a write.

Port 1

D7	D6	D5	D4	D3	D2	D1	D0
(8R)					(8W)		

Writing to Port 1 sets the data in the Port 1 output latch. Writing to an input pin does not affect the pin, but the data is stored and will be output if the direction of the pin is changed later. If the pin is used as a control signal, the pin will not be affected, but the data is stored. Reading Port 1 transfers the data in Port 1 onto the data bus. Reading an output pin or a control pin puts the data in the output latch (*not* the control signal) onto the data bus.

Interrupt Enable Register

L7	L6	L5	L4	L3	L2	L1	L0
(5R)					(5W = enable, 6W = disable)		

Interrupts are enabled by writing to the Set Interrupts Register (5W). Interrupts are disabled by writing to the Reset Interrupts Register (6W). Each bit set by the Set Interrupts Register (5W) will enable that level interrupt, and each bit set in the Reset Interrupts Register (6W) will disable that level interrupt. The user can determine which interrupts are enabled by reading the Interrupt Enable Register (5R).

Priority		Source
Highest	L0	Timer 1
	L1	Timer 2 or Port Interrupt
	L2	External Interrupt (EXTINT)
	L3	Timer 3 or Timers 3 & 5
	L4	Receiver Interrupt
	L5	Transmitter Interrupt
	L6	Timer 4 or Timers 2 & 4
Lowest	L7	Timer 5 or Port 2 Handshaking

Port 2

D7	D6	D5	D4	D3	D2	D1	D0
(9R)					(9W)		

Writing to Port 2 sets the data in the Port 2 output latch. Writing to an input pin does not affect the pin, but it does store the data in the latch. Reading Port 2 puts the input pins onto the bus or the contents of the output latch for output pins.

Timer 1-5

D7	D6	D5	D4	D3	D2	D1	D0
($0A_{16}$-$0E_{16}$ R)				($0A_{16}$-$0E_{16}$ W)			

Reading Timer N puts the contents of the timer onto the data bus. If the counter changes while $\overline{RD}$ is low, the value on the data bus will not change. If two timers are cascaded, reading the high order byte will cause the low order byte to be latched. Reading the low order byte will unlatch them both. Writing to either timer or de-cascading them also clears the latch condition. Writing to a timer sets the starting value of that timer. If two timers are cascaded, writing to the high order byte presets the low order byte to all ones. Loading only the high order byte with a value of X leads to a count of $X \cdot 256 + 255$. Timers count down continuously. If the interrupt is enabled, it occurs when the counter changes from 1 to 0. When the interrupt is set in the Interrupt Register, interrupts are disabled in the Interrupt Mask Register.

Status Register

INT	RBF	TBE	TRE	BD	PE	OE	FE
			($0F_{16}$ R)				

FE — Framing Error, Transmission Mode

If transmission mode is disabled (in Modification Register), then FE indicates a framing error. A framing error is detected during the *first* stop bit. The error is reset by reading the Status Register or by a chip reset. A framing error does not inhibit the loading of the Receiver Buffer. If RxD remains low, the receiver will assemble the next character. The false stop bit is treated as the next start bit, and no high-to-low transition on RxD is required to synchronize the receiver.

If transmission mode is enabled, then this bit is used to suggest the transmitter was sending. FE will be high if the transmitter is active during the reception of the parity bit (or last data bit for no-parity). It is reset if the transmitter is not active or by a chip reset. The bit is intended to imply that the received character is from the transmitter in half-duplex systems.

OE — Overrun Error

If the user does not read the character in the Receiver Buffer before the next character is received and transferred to this register, then the OE bit is set. The OE flag is set during the reception of the first stop bit and is cleared when the Status Register is read or when a chip reset occurs.

PE — Parity Error

A parity error is set during the first stop bit and is reset by reading the Status Register or by a chip reset.

BD — Break Detect, Break-In Detect

If BRKI in Command Register 1 is set to enable break-in detect, then BD indicates a break-in condition. If Port 16 is low during the transmission of the last stop bit, then BD will be set near the end of the last stop bit. Break-in detect can only be detected if the internal baud rate generator is used. Break-in remains set until the Status Register is read or the chip is reset.

If BRKI is low, then BD indicates a break condition on the receiver. BD is set when the first stop bit of a break is sampled and will remain set until the Status Register is read or the chip is reset. The receiver will remain idle until the next high-to-low transition on RxD. A detected break inhibits the loading of the Receiver Buffer.

TRE — Transmitter Register Empty

This status bit indicates that the Transmitter Register is busy. It is set by a chip reset and when the last stop bit has left the transmitter. It is reset when a character is loaded into the Transmitter Register. If $\overline{CTS}$ is low, the Transmitter Register will be loaded during the transmission of the start bit. If $\overline{CTS}$ is high at the end of a character, TRE will remain high and no character will be loaded into the Transmitter Register until $\overline{CTS}$ goes low. If the transmitter was inactive before a character is loaded into the Transmitter Buffer, the Transmitter Register will be empty temporarily while the buffer is full. However, the data in the buffer will be transferred to the transmitter register immediately and TRE will be cleared while TBE is set.

TBE — Transmitter Buffer Empty

TBE indicates the Transmitter Buffer is empty and is ready to accept a character. TBE is set by a chip reset or the transfer of data to the Transmitter Register and is cleared when a character is written to the transmitter buffer.

RBF — Receiver Buffer Full

RBF is set when the Receiver Buffer has been loaded with a new character during the sampling of the first stop bit. RBF is cleared by reading the receiver buffer or by a chip reset.

INT — Interrupt Pending

The INT bit reflects the state of the INT pin (pin 15) and indicates an interrupt is pending in the Interrupt Register. It is reset by $\overline{INTA}$ or by reading the Interrupt Address Register if only one interrupt is pending and by a chip reset.

FE, OE, PE, RBF, and break detect all generate a level 4 interrupt when the receiver samples the first stop bit. TRE, TBE, and break-in detect generate a level 5 interrupt. TRE generates an interrupt when TBE is set and the Transmitter Register finishes transmitting. The

break-in detect interrupt is issued at the same time as TBE or TRE.

Modification Register

0	RS4	RS3	RS2	RS1	RS0	TME	DSC

($0F_{16}$ W)

DSC — Disable Start Bit Check

DSC disables the receiver's start bit check. In this state the receiver will not be reset if RxD is not low at the center of the start bit. This function is disabled by a chip reset.

TME — Transmission Mode Enable

TME enables transmission mode and disables framing error detection. A chip reset disables transmission mode and enables framing error detection.

RS0, RS1, RS2, RS3, RS4 — Receiver Sample Time

The number in RSn alters when the receiver samples RxD. A chip reset sets this value to 0 which is the center of the bit (sample time = 16). The receiver sample time can be modified only if the receiver is *not* clocked by $\overline{RxC}$.

				Sample Time	
RS4	RS3	RS2	RS1	RS0 = 0	RS0 = 1
0	1	1	1	2	1
0	1	1	0	[illegible]	3
0	1	0	1	[illegible]	5
0	1	0	0	[illegible]	7
0	0	1	1	10	[illegible]
0	0	1	0	12	11
0	0	0	1	14	13
0	0	0	0	16	15
1	1	1	1	18	17
1	1	1	0	20	19
1	1	0	1	22	21
1	1	0	0	24	23
1	0	1	1	26	25
1	0	1	0	[illegible]	27
1	0	0	1	30	[illegible]
1	0	0	0	32	31

8271/8271-6
PROGRAMMABLE FLOPPY DISK CONTROLLER

- **IBM 3740 Soft Sectored Format Compatible**
- **Programmable Record Lengths**
- **Multi-Sector Capability**
- **Maintain Dual Drives with Minimum Software Overhead Expandable to 4 Drives**
- **Automatic Read/Write Head Positioning and Verification**
- **Internal CRC Generation and Checking**
- **Programmable Step Rate, Settle-Time, Head Load Time, Head Unload Index Count**
- **Fully MCS-80™ and MCS-85™ Compatible**
- **Single +5V Supply**
- **40-Pin Package**

The Intel® 8271 Programmable Floppy Disk Controller (FDC) is an LSI component designed to interface one to 4 floppy disk drives to an 8-bit microcomputer system. Its powerful control functions minimize both hardware and software overhead normally associated with floppy disk controllers.

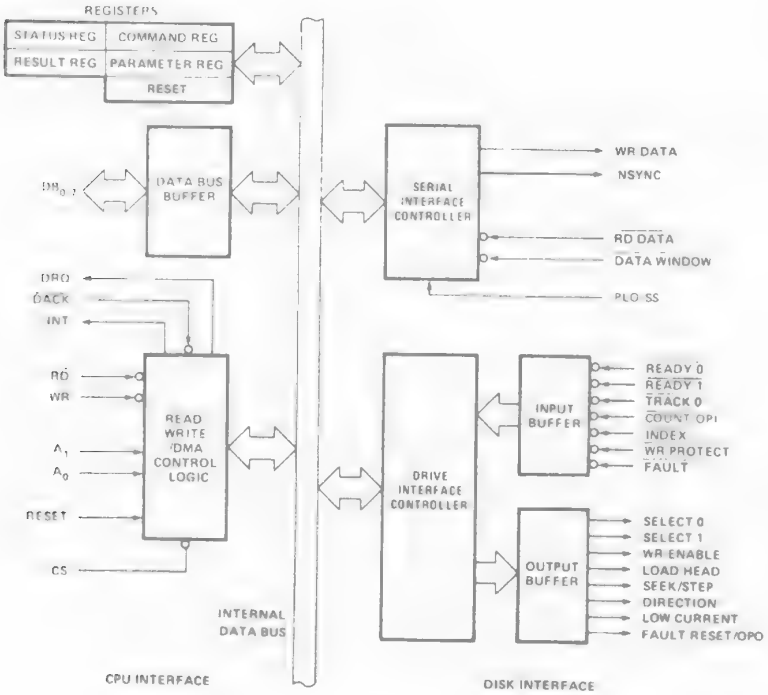


Figure 1. Block Diagram

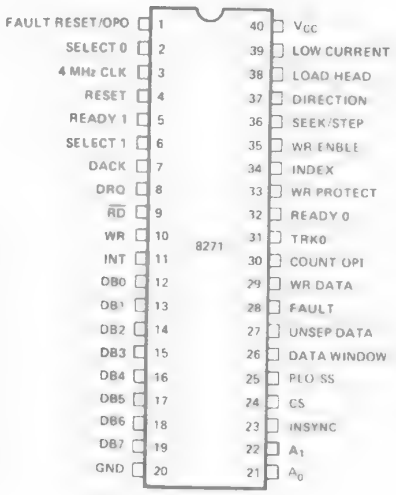


Figure 2. Pin Configuration

Table 1. Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
PLO/SS	25	I	**Phase-Locked Oscillator/ Single Shot:** This pin is used to specify the type of data separator used.
Write Data	29	O	**Write Data:** Composite write data.
$\overline{\text{Unseparated Data}}$	27	I	**Unseparated Data:** This input is the unseparated data and clocks.
Data Window	26	I	**Data Window:** This is a data window established by a single-shot or phase-locked oscillator data separator.
INSYNC	23	O	**Input Synchronization:** This line is high when 8271 has attained input data synchronization, by detecting 2 bytes of zeros followed by an expected Address Mark. It will stay high until the end of the ID or data field.

FUNCTIONAL DESCRIPTION

General

The 8271 Floppy Disk Controller (FDC) interfaces either two single or one dual floppy drive to an eight bit microprocessor and is fully compatible with Intel's new high performance MCS-85 microcomputer system. With minimum external circuitry, this innovative controller supports most standard, commonly-available flexible disk drives including the mini-floppy.

The 8271 FDC supports a comprehensive soft sectored format which is IBM 3740 compatible and includes provision for the designating and handling of bad tracks. It is a high level controller that relieves the CPU (and user) of many of the control tasks associated with implementing a floppy disk interface. The FDC supports a variety of high level instructions which allow the user to store and retrieve data on a floppy disk without dealing with the low level details of disk operation.

In addition to the standard read/write commands, a scan command is supported. The scan command allows the user program to specify a data pattern and instructs the FDC to search for that pattern on a track. Any application that is required to search the disk for information (such as point of sale price lookup, disk directory search, etc.), may use the scan command to reduce the CPU overhead. Once the scan operation is initiated, no CPU intervention is required.

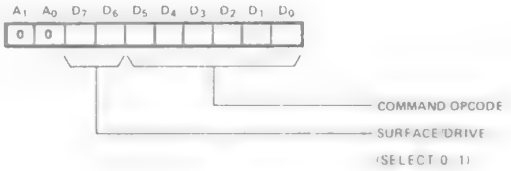
CPU Interface Description

This interface minimizes CPU involvement by supporting a set of high level commands and both DMA and non-DMA type data transfers and by providing hierarchical status information regarding the result of command execution.

The CPU utilizes the control interface (see the Block diagram) to specify the FDC commands and to determine the result of an executed command. This interface is supported by five Registers which are addressed by the CPU via the A_1, A_0, $\overline{RD}$ and $\overline{WR}$ signals. If an 8080 based system is used, the $\overline{RD}$ and $\overline{WR}$ signals can be driven by the 8228's $\overline{I/OR}$ and $\overline{I/OW}$ signals. The registers are defined as follows:

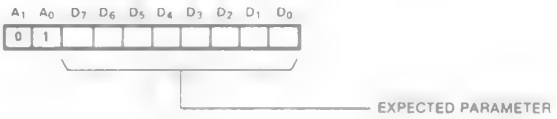
Command Register

The CPU loads an appropriate command into the Command Register which has the following format:



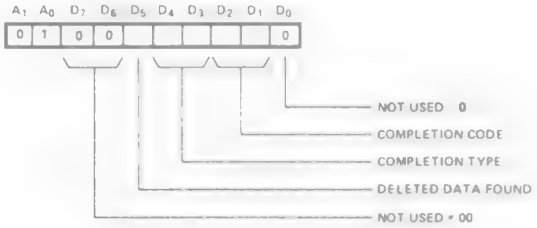
Parameter Register

Accepts parameters of commands that require further description; up to five parameters may be required, example:



Result Register

The Result Register is used to supply the outcome of FDC command execution (such as a good/bad completion) to the CPU. The standard Result byte format is:



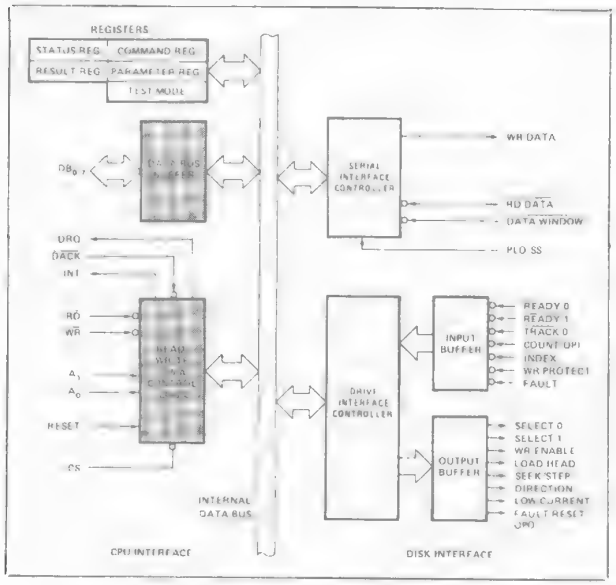
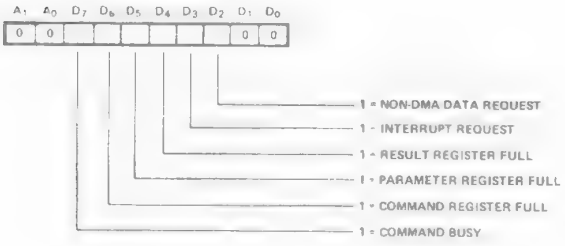


Figure 3. 8271 Block Diagram Showing CPU Interface Functions

Status Register

Reflects the state of the FDC.



Reset Register

Allows the 8271 to be reset by the program. Reset must be active for 11 or more chip clocks.

INT (Interrupt Line)

Another element of the control interface is the Interrupt line (INT). This line is used to signal the CPU that an FDC operation has been completed. It remains active until the result register is read.

DMA Operation

The 8271 can transfer data in either DMA or non DMA mode. The data transfer rate of a floppy disk drive is high enough (one byte every 32 µsec) to justify DMA transfer. In DMA mode the elements of the DMA interface are:

DRQ: DMA Request:
The DMA request signal is used to request a transfer of data between the 8271 and memory.

$\overline{\text{DACK}}$: DMA Acknowledge:
The DMA acknowledge signal notifies the 8271 that a DMA cycle has been granted.

$\overline{\text{RD}}$, $\overline{\text{WR}}$: Read, Write
The read and write signals are used to specify the direction of the data transfer.

DMA transfers require the use of a DMA controller such as the Intel®8257. The function of the DMA controller is to provide sequential addresses and timing for the transfer at a starting address determined by the CPU. Counting of data block lengths is performed by the FDC.

To request a DMA transfer, the FDC raises DRQ. DACK and RD enable DMA data onto the bus (independently of CHIP SELECT). DACK and WR transfer DMA data to the FDC. If a data transfer request (read or write) is not serviced within 31 µsec, the command is cancelled, a late DMA status is set, and an interrupt is generated. In DMA mode, an interrupt is generated at the completion of the data block transfer.

When configured to transfer data in non-DMA mode, the CPU must pass data to the FDC in response to the non-DMA data requests indicated by the status word. The data is passed to and from the chip by asserting the DACK and the RD or WR signals. Chip select should be inactive (HIGH).

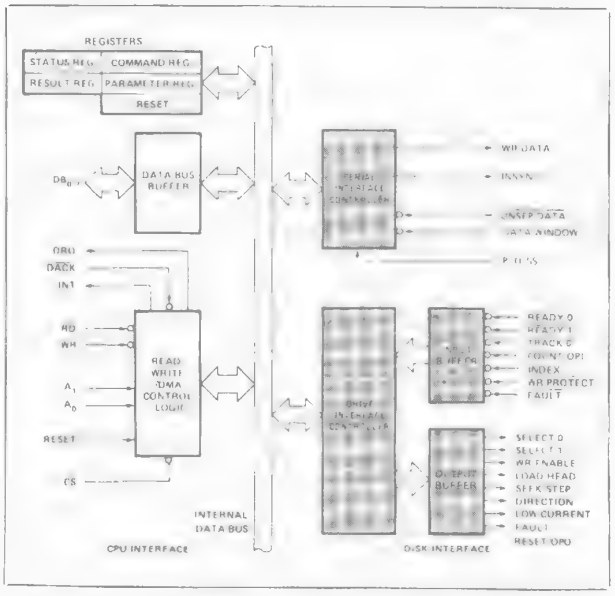


Figure 4. 8271 Block Diagram Showing Disk Interface Functions

Disk Drive Interface

The 8271 disk drive interface supports the high level command structure described in the Command Description section. The 8271 maintains the location of bad tracks and the current track location for two drives. However, with minor software support, this interface can support four drives by expanding the two drive select lines (select 0, select 1) with the addition of minimal support hardware.

The FDC Disk Drive Interface has the following major functions.

READ FUNCTIONS

Utilize the user supplied data window to obtain the clock and data patterns from the unseparated read data.

Establish byte synchronization.

Compute and verify the ID and data field CRCs.

WRITE FUNCTIONS

Encode composite write data.

Compute the ID and data field CRCs and append them to their respective fields.

CONTROL FUNCTIONS

Generate the programmed step rate, head load time, head settling time, head unload delay, and monitor drive functions.

Data Separation

The 8271 needs only a data window to separate the data from the composite read data as well as to detect missing clocks in the Address Marks.

The window generation logic may be implemented using either a single-shot separator or a phase-locked oscillator.

Single-Shot Separator

The single-shot separator approach is the lowest cost solution.

The FDC samples the value of Data Window on the leading edge of Unseparated Data and determines whether the delay from the previous pulse was a half or full bit-cell (high input = full bit-cell, low input = half bit-cell). PLO/SS should be tied to Ground.

Insync Pin

This pin gives an indication of whether the 8271 is synchronized with the serial data stream during read operations. This pin can be used with a phase-locked oscillator for soft and hard locking.

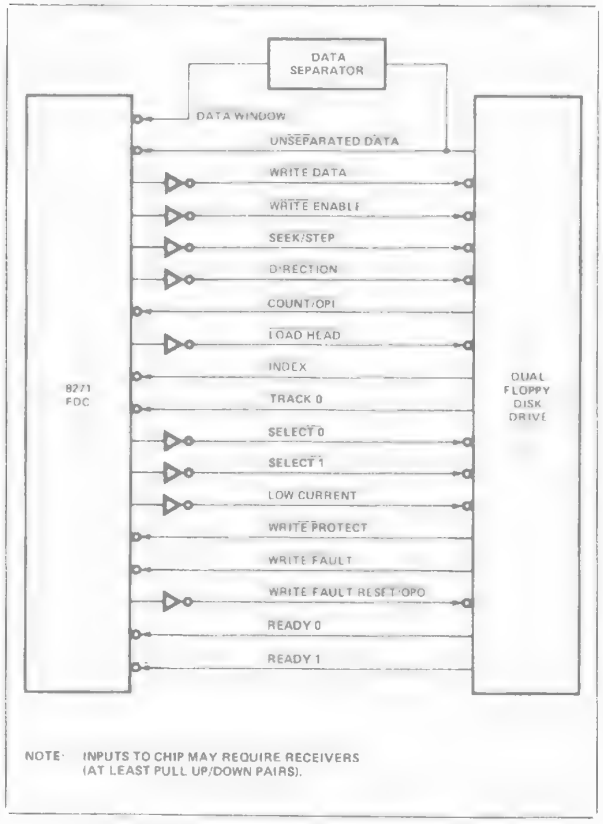
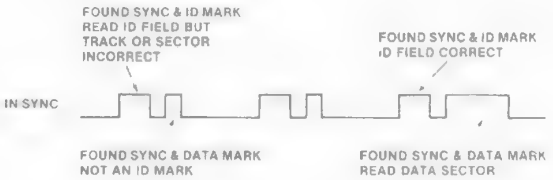


Figure 5. 8271 Disk Drive Interface



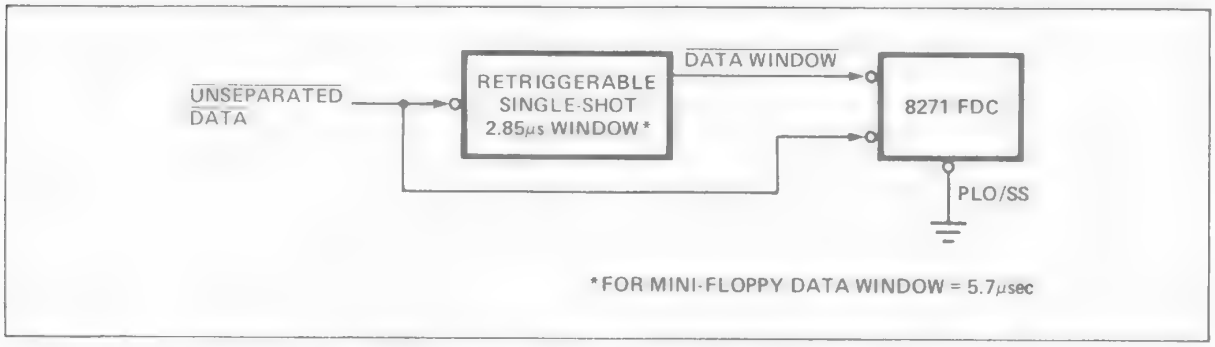


Figure 6. Single-Shot Data Separator Block Diagram

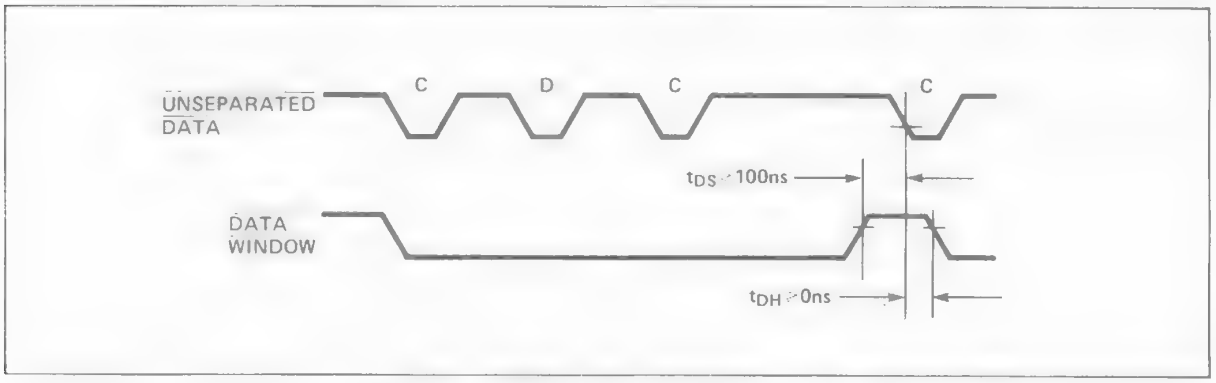


Figure 7. Single-Shot Data Window Timing

Phase-Locked Oscillator Separator

The FDC samples the value of Data Window on the leading edge of Unseparated Data and determines whether the pulse represents a Clock or Data Pulse.

PLO/SS should be tied to V_{CC} (+5V).

Insync may be used to provide soft and hard locking control for the phase-locked oscillator.

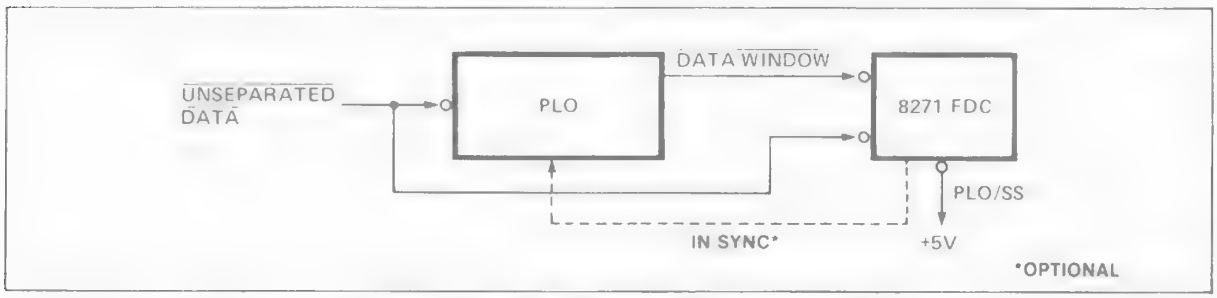


Figure 8. PLO Data Separator Block Diagram

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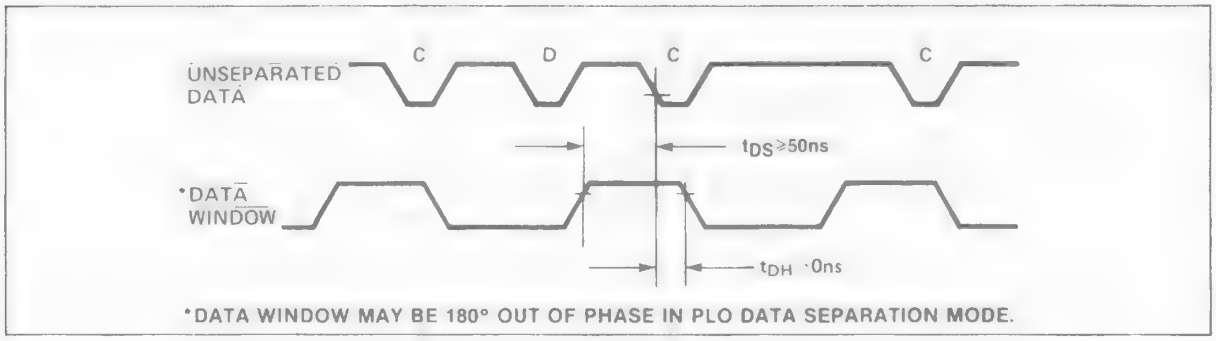


Figure 9. PLO Data Window Timing

Disk Drive Control Interface

The disk drive control interface performs the high level and programmable flexible disk drive operations. It custom tailors many varied drive performance parameters such as the step rate, settling time, head load time, and head unload index count. The following is the description of the control interface.

Write Enable

The Write Enable controls the read and write functions of a flexible disk drive. When Write Enable is a logical one, it enables the drive write electronics to pass current through the Read/Write head. When Write Enable is a logical zero, the drive Write circuitry is disabled and the Read/Write head detects the magnetic flux transitions recorded on a diskette. The write current turn-on is as follows.

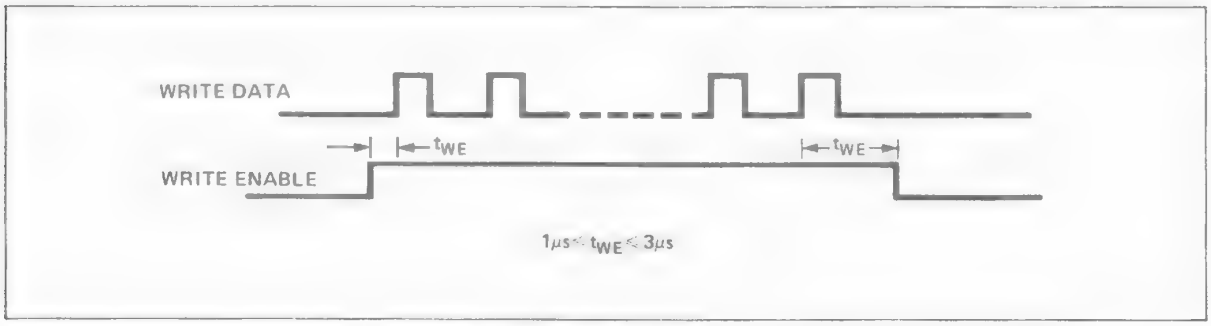


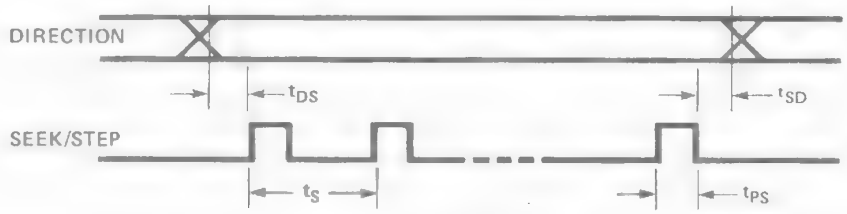
Figure 10. Write Enable Timing

Seek Control

Seek Control is accomplished by Seek/Step, Direction, and Count pins and can be implemented two ways to provide maximum flexibility in the subsystem design. One instance is when the programmed step rate is not equal to zero. In this case, the 8271 uses the Seek/Step and Direction pins (the Seek/Step pin becomes a Step pin). Programmable Step timing parameters are shown.

Another instance is when the programmable step rate is equal to zero, in which case the 8271 holds the seek line high until the appropriate number of user-supplied step pulses have been counted on the count input pin.

The Direction pin is a control level indicating the direction in which the R/W head is stepped. A logic high level on this line moves the head toward the spindle (step-in). A logic low level moves the head away from the spindle (step-out).

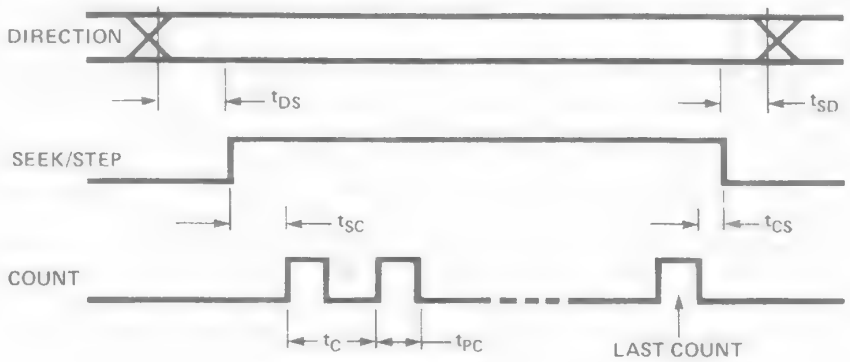


$t_{PS}=t_{DS}=t_{SD}=10\mu s$

STANDARD: $1ms \leq t_S \leq 255ms$

MINI-FLOPPY: $2ms \leq t_S \leq 510ms$

Figure 11. Seek Timing



$t_{DS}=t_{SD}=t_{CS}=10\mu s$

$t_{SC} = 1\mu s$

$t_{PC} = 20\mu s$

$t_C > 1ms$

Figure 12. Seek/Step/Count Timing

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Head Seek Settling Time

The 8271 allows the head settling time to be programmed from 0 to 255ms, in increments of 1ms.

The head settling time is defined as the interval of time from completion of the last step to the time when reading or writing on the diskette is possible (R/W Enable). The R/W head is assumed loaded.

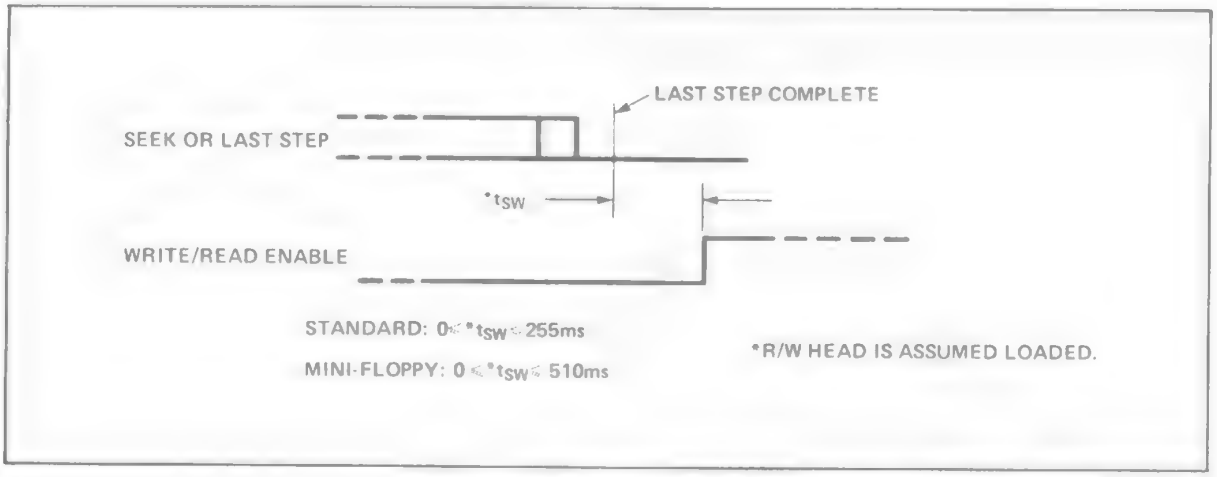


Figure 13. Head Load Settling Timing

Load Head

When active, load head output pin causes the drive's read/write head to be loaded on the diskette. When the head is initially loaded, there is a programmed delay (0 to 60ms in 4ms increments) prior to any read or write operation. Provision is also made to unload the head following an operation within a programmed number of diskette revolutions.

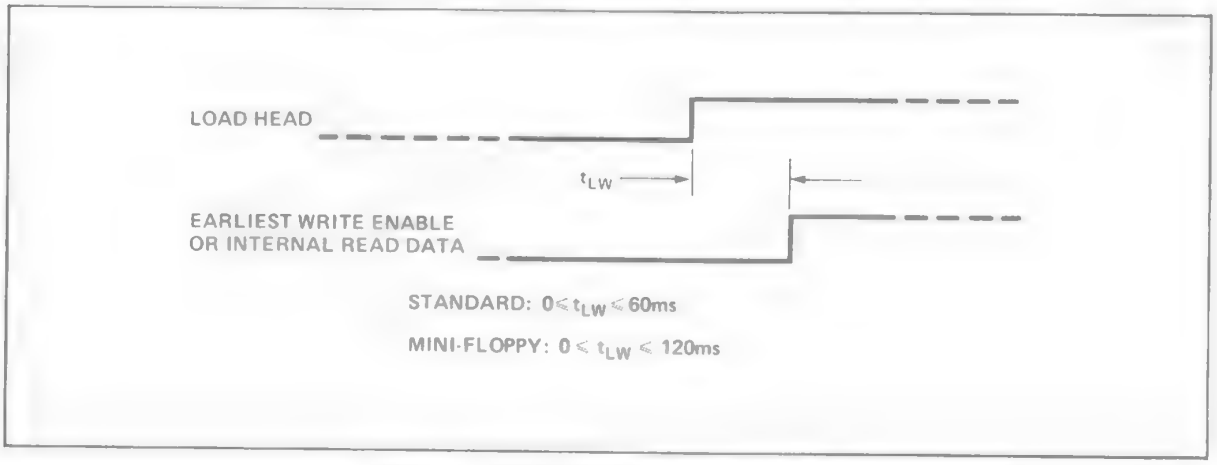


Figure 14. Head Load to Read/Write Timing

Index

The Index input is used to determine "Sector not found" status and to initiate format track/read ID commands and head unload Index and Count operations.

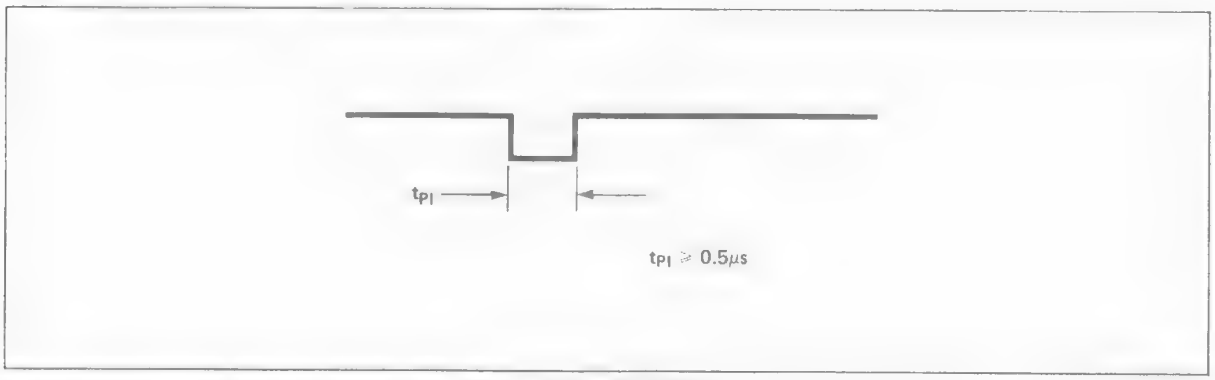


Figure 15. Index Timing

Track 0

This input pin indicates that the diskette is at track 0. During any seek operation, the stepping out of the actuator ceases when the track 0 pin becomes active.

Select 1, 0

Only one drive may be selected at a time. The Input/Output pins that must be externally qualified with Select 0 and Select 1 are:

Unseparated Data
Data Window
Write Enable
Seek/Step
Count/Optional Input
Load Head
Track 0
Low Current
Write Protect
Write Fault
Fault Reset/Optional Output
Index

When a new set of select bits is specified by a new command or the FDC finishes the index count before head unload, the following pins will be set to the 0 state:

Write Enable (35)
Seek/Step (36)
Direction (37)
Load Head (38)
Low Head Current (39)

The select pins will be set to the state specified by the command or both are set to zero following the index count before head unload.

Low Current

This output pin is active whenever the physical track location of the selected drive is greater than 43. Generally this signal is used to enable compensation for the lower velocities encountered while recording on the inner tracks.

Write Protect

The 8271 will not write to a disk when this input pin is active and will interrupt the CPU if a Write attempt is made. Operations which check Write Protect are aborted if the Write Protect line is active.

This signal normally originates from a sensor which detects the presence or absence of the Write Protect hole in the diskette jacket.

Write Fault and Write Fault Reset

The Write Fault input is normally latched by the drive and indicates any condition which could endanger data integrity. The 8271 interrupts the CPU anytime Write Fault is detected during an operation and immediately resets the Write Enable, Seek/Step, Direction, and Low Current signals. The write fault condition can be cleared by using the write fault reset pin. If the drive being used does not support write fault, then this pin should be connected to V_{CC} through a pull-up resistor.

Ready 1, 0

These two pins indicate the functional status of the disk drives. Whenever an operation is attempted on a drive which is not ready, an interrupt is generated. The interface continually monitors this input during an operation and if a Not Ready condition occurs, immediately terminates the operation. Note that the 8271 latches the Not Ready condition and it can only be reset by the execution of a Read Drive Status command. For drives that do not support a ready signal, either one can be derived with a one shot and the index pulse, or the ready inputs can be grounded and Ready determined through some software means.

PRINCIPLES OF OPERATION

As an 8080 peripheral device, the 8271 accepts commands from the CPU, executes them and provides a RESULT back to the 8080 CPU at the end of command execution. The communication with the CPU is established by the activation of $\overline{CS}$ and $\overline{RD}$ or $\overline{WR}$. The A_1, A_0 inputs select the appropriate registers on the chip:

$\overline{DACK}$	$\overline{CS}$	A_1	A_0	$\overline{RD}$	$\overline{WR}$	Operation
1	0	0	0	0	1	Read Status
1	0	0	0	1	0	Write Command
1	0	0	1	0	1	Read Result
1	0	0	1	1	0	Write Parameter
1	0	1	0	1	0	Write Reset Reg.
0	1	X	X	1	0	Write Data
0	1	X	X	0	1	Read Data
0	0	X	X	X	X	Not Allowed

The FDC operation is composed of the following sequence of events.

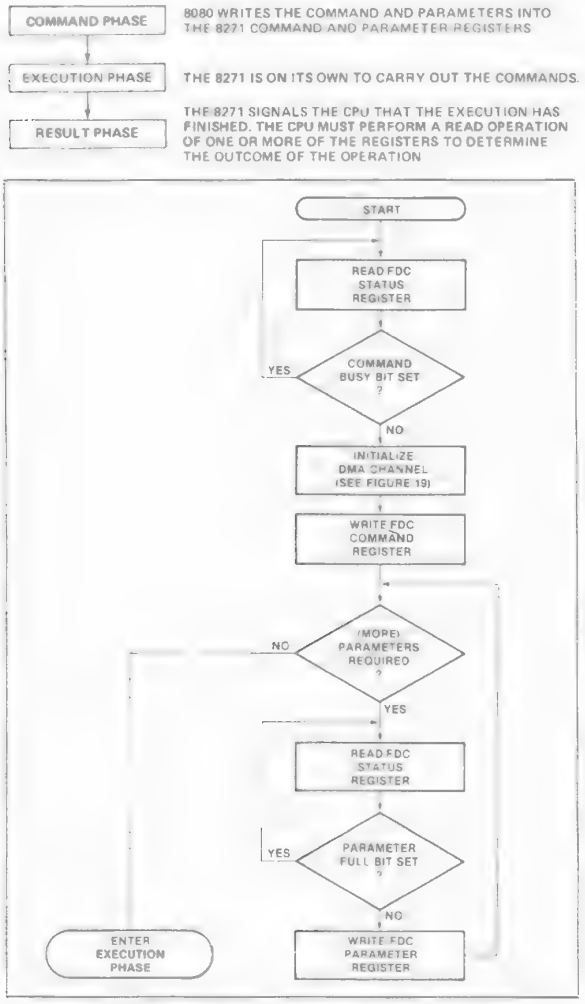


Figure 16. Passing the Command and Parameters to the 8271

The Command Phase

The software writes a command to the command register. As a function of the command issued, from zero to five parameters are written to the parameter register. Refer to diagram showing a flow chart of the command phase. Note that the flow chart shows that a command may not be issued if the FDC status register indicates that the device is busy. Issuing a command while another command is in progress is illegal. The flow chart also shows a parameter buffer full check. The FDC status indicates the state of the parameter buffer. If a parameter is issued while the parameter buffer is full, the previous parameter is over written and lost.

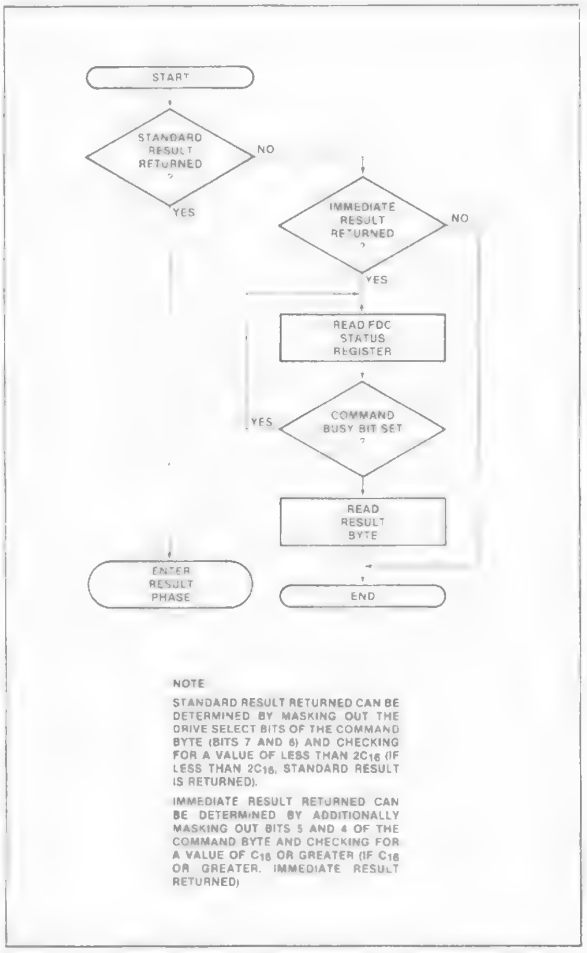


Figure 17. Checking for Result Type Following 8271 Command and Parameters

The Execution Phase

During the execution phase the operation specified during the command phase is performed. During this phase, there is no CPU involvement if the system utilizes DMA for the data transfers. The execution phase of each command is discussed within the detailed command descriptions. The following table summarizes many of the basic execution phase characteristics.

EXECUTION PHASE BASIC CHARACTERISTICS

The following table summarizes the various commands with corresponding execution phase characteristics.

Table 2. Execution Phase Basic Characteristics

COMMANDS	1 Deleted Data	2 Head	3 Ready	4 Write/ Protect	5 Seek	6 Seek Check	7 Result	8 Completion Interrupt
SCAN DATA	SKIP	LOAD	✓	x	YES	YES	YES	YES
SCAN DATA AND DEL DATA	XFER	LOAD	✓	x	YES	YES	YES	YES
WRITE DATA	x	LOAD	✓	✓	YES	YES	YES	YES
WRITE DEL DATA	x	LOAD	✓	✓	YES	YES	YES	YES
READ DATA	SKIP	LOAD	✓	x	YES	YES	YES	YES
READ DATA AND DEL DATA	XFER	LOAD	✓	x	YES	YES	YES	YES
READ ID	x	LOAD	✓	x	YES	NO	YES	YES
VERIFY DATA AND DEL DATA	XFER	LOAD	✓	x	YES	YES	YES	YES
FORMAT TRACK	x	LOAD	✓	✓	YES	NO	YES	YES
SEEK	x	LOAD	y	x	YES	NO	YES	YES
READ DRIVE STATUS	x	–	x	x	NO	NO	NOTE 5	NO
SPECIFY	x	–	x	x	NO	NO	NO	NO
RESET	x	UNLOAD	x	x	NO	NO	NO	NO
R SP REGISTERS	x	–	x	x	NO	NO	NOTE 6	NO
W SP REGISTERS	x	–	x	x	NO	NO	NO	NO

Note 1. x = DON'T CARE 2. "✓" → check 3. "–" → No change 4. "y" = Check at end of operation 5. See "READ DRIVE STATUS" command. 6. See "READ SPECIAL REGISTER" command

Explanation of the execution phase characteristics table.

1. Deleted Data Processing

   If deleted data is encountered during an operation that is marked skip in the table, the deleted data record is not transferred into memory, but the record is counted. For example, if the command and parameters specify a read of five records and one of the records was written with a deleted data mark, four records are transferred to memory. The deleted data flag is set in the result byte. However, if the operation is marked transfer, all data is transferred to memory regardless of the type of data mark.

2. Head

   The Head column in the table specifies whether the Read/Write head will be loaded or not. If the table specifies load, the head is loaded after it is positioned over the track. The head loaded by a command remains loaded until the user specified number of index pulses have occurred.

3. Ready

   The Ready column indicates if the ready line (Ready 1, Ready 0) associated with the selected drive is checked. A not ready state is latched by the 8271 until the user executes a read status command.

4. Write Protect

   The operations that are marked check Write Protect are immediately aborted if Write Protect line is active at the beginning of an operation.

5. Seek

   Many of the 8271 commands cause a seek to the desired track. A current track register is maintained for each drive or surface.

6. Seek Check

   Operations that perform Seek Check verify that selected data in the ID field is correct before the 8271 accesses the data field.

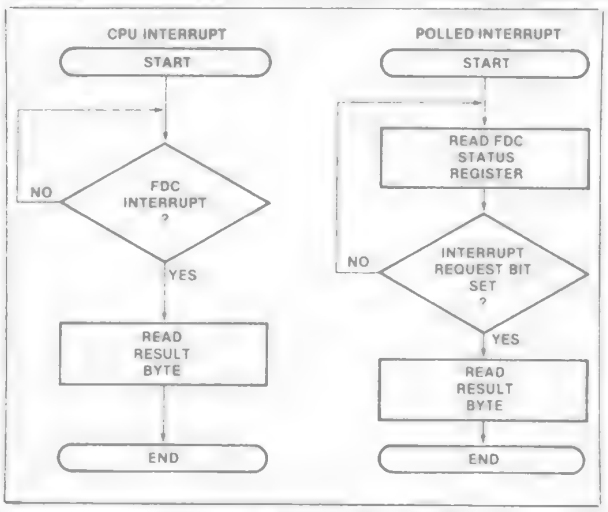


Figure 18. Getting the Result

The Result Phase

During the Result Phase, the FDC notifies the CPU of the outcome of the command execution. This phase may be initiated by:

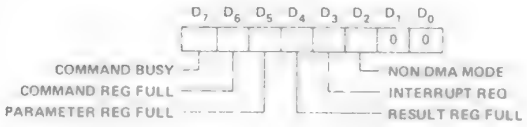
1. The successful completion of an operation.
2. An error detected during an operation.

PROGRAMMING

A_1	A_0	CS RD	CS WR
0	0	Status Reg	Command Reg
0	1	Result Reg	Parameter Reg
1	0	—	Reset Reg
1	1	—	—

STATUS REGISTER

FDC Status



Bit 7: Command Busy

The command busy bit is set on writing to the command register. Whenever the FDC is busy processing a command, the command busy bit is set to a one. This bit is set to zero after the command is completed.

Bit 6: Command Full

The command full bit is set on writing to the command buffer and cleared when the FDC begins processing the command.

Bit 5: Parameter Full

This bit indicates the state of the parameter buffer. This bit is set when a parameter is written to the FDC and reset after the FDC has accepted the parameter.

Bit 4: Result Full

This bit indicates the state of the result buffer. It is valid only after Command Busy bit is low. This bit is set when the FDC finishes a command and is reset after the result byte is read by the CPU. The data in the result buffer is valid only after the FDC has completed a command. Reading the result buffer while a command is in progress yields no useful information.

Bit 3: Interrupt Request

This bit reflects the state of the FDC INT pin. It is set when FDC requests attention as a result of the completion of an operation or failure to complete an intended operation. This bit is cleared by reading the result register.

Bit 2: Non-DMA Data Request

When the FDC is utilized without a DMA controller, this bit is used to indicate FDC data requests. Note that in the non-DMA mode, an interrupt is generated (interrupt request bit is set) with each data byte written to or read from the diskette.

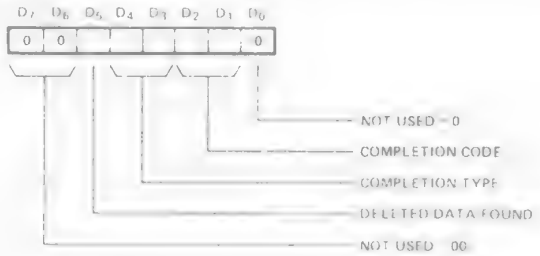
Bits 1 and 0:

Not used (zero returned).

After reading the Status Register, the CPU then reads the Result Register for more information.

THE RESULT REGISTER

This byte format facilitates the use of an address table to look up error routines and messages. The standard result byte format is:



Bits 7 and 6:

Not used (zero returned).

Bit 5:

Deleted Data Found: This bit is set when deleted data is encountered during a transaction.

Bits 4 and 3: Completion Type

The completion type field provides general information regarding the outcome of an operation.

The completion type field provides general information regarding the outcome of an operation.

Completion Type	Event
00	Good Completion — No Error
01	System Error — recoverable errors;
10	operator intervention probably required for recovery.
11	Command/Drive Error — either a program error or drive hardware failure.

Bits 2 and 1: Completion Code

The completion code field provides more detailed information about the completion type (See Table).

Completion Type	Completion Code	Event
00	00	Good Completion/ Scan Not Met
00	01	Scan Met Equal
00	10	Scan Met Not Equal
00	11	——
01	00	Clock Error
01	01	Late DMA
01	10	ID CRC Error
01	11	Data CRC Error
10	00	Drive Not Ready
10	01	Write Protect
10	10	Track 0 Not Found
10	11	Write Fault
11	00	Sector Not Found
11	01	——
11	10	——
11	11	——

It is important to note the hierarchical structure of the result byte. In very simple systems where only a GO-NO GO result is required, the user may simply branch on a zero result (a zero result is a good completion). The next level of complexity is at the completion type interface. The completion type supplies enough information so that the software may distinguish between fatal and non-fatal errors. If a completion type 01 occurs, ten retries should be performed before the error is considered unrecoverable.

The Completion Type/Completion Code interface supplies the greatest detail about each type of completion. This interface is used when detailed information about the transaction completion is required.

Bit 0:

Not used (zero returned).

Table 3. Completion Code Interpretation

Definition	Interpretation
Successful Completion/ Scan Not Met	The diskette operation specified was completed without error. If scan operation was specified, the pattern scanned was not found on the track addressed
Scan Met Equal	The data pattern specified with the scan command was found on the track addressed with the specified comparison, and the equality was met.
Scan Met Not Equal	The data pattern specified with the scan command was found with the specified comparison on the track addressed, but the equality was not met.
Clock Error	During a diskette read operation, a clock bit was missing (dropped). Note that this function is disabled when reading any of the ID address marks (which contain missing clock pulses). If this error occurs, the operation is terminated immediately and an interrupt is generated
Late DMA	During either a diskette read or write operation, the data channel did not respond within the allotted time interval to prevent data from being overwritten or lost. This error immediately terminates the operation and generates an interrupt.
ID Field CRC Error	The CRC word (two bytes) derived from the data read in an ID field did not match the CRC word written in the ID field when the track was formatted. If this error occurs, the associated diskette operation is prevented and no data is transferred
Data Field CRC Error	During a diskette read operation, the CRC word derived from the data field read did not match the data field CRC word previously written. If this error occurs, the data read from the sector should be considered invalid
Drive Not Ready	The drive addressed was not ready. This indication is caused by any of the following conditions: 1. Drive not powered up 2. Diskette not loaded 3. Non-existent drive addressed 4. Drive went not ready during an operation Note that this completion code is cleared only through an FDC read drive status command.
Write Protect	A diskette write operation was specified on a write protected diskette. The intended write operation is prevented and no data is written on the diskette
Track 00 Not Found	During a seek to track 00 operation, the drive failed to provide a track 00 indication after being stepped 255 times.
Write Fault	This error is dependent on the drive supported and indicates that the fault input to the FDC has been activated by the drive
Sector Not Found	Either the sector addressed could not be found within one complete revolution of the diskette (two index marks encountered) or the track address specified did not match the track address contained in the ID field. Note that when the track address specified and the track address read do not match, the FDC automatically increments its track address register (stepping the drive to the next track) and again compares the track addresses. If the track addresses still do not match, the track address register is incremented a second time and another comparison is made before the sector not found completion code is set.

INITIALIZATION

Reset Command

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
PAR:	1	0	0	0	0	0	0	0	0	1
PAR:	1	0	0	0	0	0	0	0	0	0

Function: The Reset command emulates the action of the reset pin. It is issued by outputting a one followed by a zero to the Reset register.

1. The drive control signals are forced low.
2. An in-progress command is aborted.
3. The FDC status register flags are cleared
4. The FDC enters an idle state until the next command is issued.

Reset must be active for 10 or more clock cycles.

SPECIFY COMMAND

Many of the interface characteristics of the FDC are specified by the system's software. Prior to initiating any drive operation command, the software must execute the three specify commands. There are two types of specify commands selectable by the first parameter issued.

First Parameter	Specify Type
$0D_H$	Initialization
10_H	Load bad Tracks Surface '0'
18_H	Load bad Tracks Surface '1'

The Specify command is used prior to performing any diskette operation (including formatting of a diskette) to define the drive's inherent operating characteristics and also is used following a formatting operation or installation of another diskette to define the locations of bad tracks. Since the Specify command only loads internal registers within the 8271 and does not involve an actual diskette operation, command processing is limited to only Command Phase. Note that once the operating characteristics and bad tracks have been specified for a given drive and diskette, redefining these values need only be done if a diskette with unique bad tracks is to be used or if the system is powered down.

Initialization:

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD	0	0	0	0	1	1	0	1	0	1
PAR	0	1	0	0	0	0	1	1	0	1
PAR	0	1	STEP RATE*							
PAR:	0	1	HEAD SETTLING TIME*							
PAR	0	1	INDEX CNT BEFORE HEAD UNLOAD*				HEAD LOAD TIME*			

*Note: Mini-floppy parameters are doubled

Parameter 0 — $0D_H$ = Select Specify Initialization.
Parameter 1 — D_7-D_0 = Step Rate (0-255ms in 1ms steps).
Parameter 2 — D_7-D_0 = Head Settling Time (0-255ms in 1 ms steps). {0 – 510ms in 2ms steps} () = standard, {} = mini
Parameter 3 — D_7-D_4 – Index Count — Specifies the number of Revolutions (0-14) which are to occur before the FDC automatically unloads the R/W head. If 15 is specified, the head remains loaded.
D_3-D_0 = Head Load Time (0-60ms in steps of 4ms). {0 – 120ms in 8ms steps} () = standard, {} = mini

Load Bad Tracks

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD	0	0	0	0	1	1	0	1	0	1
PAR	0	1	0	0	0	1	1	0	0	0
PAR	0	1	BAD TRACK NO. 1							
PAR.	0	1	BAD TRACK NO. 2							
PAR	0	1	CURRENT TRACK							

Parameter 0: 10_H = Load Surface zero bad tracks
18_H = Load Surface one bad track

Parameter 1:
Bad track address number 1 (Physical Address).

It is recommended to program both bad tracks and current track to FF_H during initialization.

SEEK COMMAND

The seek command moves the head to the specified track without loading the head or verifying the track.

The seek operation uses the specified bad tracks to compute the physical track address. This feature insures that the seek operation positions the head over the correct track.

When a seek to track zero is specified, the FDC steps the head until the track 00 signal is detected.

If the track 00 signal is not detected within $(FF)_H$ steps, a track 0 not found error status is returned.

A seek to track zero is used to position the read/write head when the current head position is unknown (such as after a power up).

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD	0	0	SEL 1	SEL 0	1	0	1	0	0	1
PAR	0	1	TRACK ADDRESS 0 255							

Seek operations are not verified. A subsequent read or write operation must be performed to determine if the correct track is located.

READ DRIVE STATUS COMMAND

This command is used to interrogate the drive status. Upon completion the result register will hold the final drive status.

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	SEL 1	SEL 0	1	0	1	1	0	0

RESULT: EACH BIT INDICATES CURRENT STATE OF INPUT PINS.

A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
0	1	—	RDY 1*	WR FAULT	INDEX	WR PROT	RDY 0*	TRACK 0	CNT / OPI

IF A DRIVE NOT READY RESULT IS RETURNED, THE READ STATUS MUST BE ISSUED TO CLEAR THE CONDITION

*Note the two ready bits are zero latching. Therefore, to clear the drive not ready condition, assuming the drive is ready, and to detect it via software, one must issue this command twice.

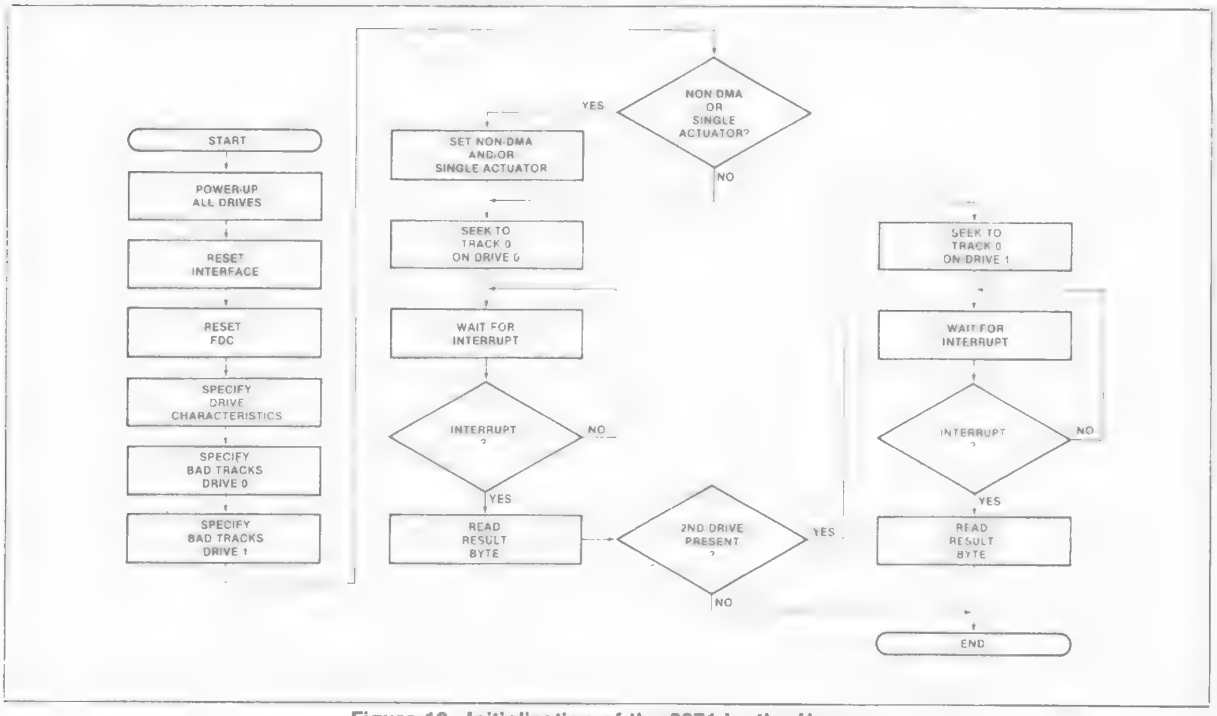


Figure 19. Initialization of the 8271 by the User

Read/Write Special Registers

This command is used to access special registers within the 8271.

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD	0	0	SEL 1	SEL 0	COMMAND OPCODE					
PAR	0	1	REGISTER ADDRESS							

Command code:

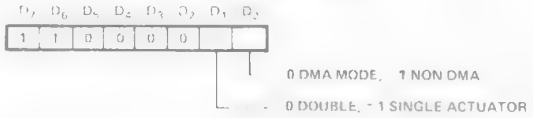
3D$_H$ Read Special Register
3A$_H$ Write Special Register

For both commands, the first parameter is the register address; for Write commands a second parameter specifies data to be written. Only the Read Special Register command supplies a result.

Table 4. Special Registers

Description	Register Address in Hex	Comment
Scan Sector Number	06	See Scan Description
Scan MSB of Count	14	See Scan Description
Scan LSB of Count	13	See Scan Description
Surface 0 Current Track	12	
Surface 1 Current Track	1A	
Mode Register	17	See Mode Register Description
Drive Control Output Port	23	See Drive Output Port Description
Drive Control Input Port	22	See Drive Input Port Description
Surface 0 Bad Track 1	10	
Surface 0 Bad Track 2	11	
Surface 1 Bad Track 1	18	
Surface 1 Bad Track 2	19	

Mode Register Write Parameter Format



Bits 6 & 7

Must be one.

Bits 5-2

(Not used). Must be set to zero.

*Bit 1

Double/Single Actuator: Selects single or double actuator mode. If the single actuator mode is selected, the FDC assumes that the physical track location of both disks is always the same. This mode facilitates control of a drive which has a single actuator mechanism to move two heads.

*Bit 0

Data Transfer Mode: This bit selects the data transfer mode. If this bit is a zero, the FDC operates in the DMA mode (DMA Request/ACK). If this bit is a one, the FDC operates in non-DMA mode. When the FDC is operating in DMA mode, interrupts are generated at the completion of commands. If the non-DMA mode is selected, the FDC generates an interrupt for every data byte transferred.

*Bits 0 and 1 are initialized to zero.

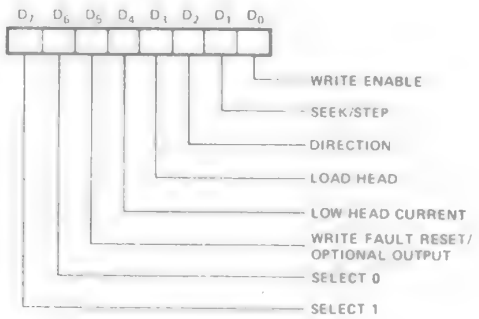
Non-DMA Transfers in DMA Mode

If the user desires, he may retain the use of interrupts generated upon command completions. This mode is accomplished by selecting the DMA capability, but using the DMA REQ/ACK pins as effective INT and CS signals, respectively.

Drive Control Input Port

Reading this port will give the CPU exactly the data that the FDC sees at the corresponding pins. Reading this port will update the drive not ready status, but will not clear the status. (See Read Drive Status Command for Bit locations.)

Drive Control Output Port Format



Each of these signals correspond to the chip pin of the same name. On standard-sized drives with write fault detection logic, bit 5 is set to generate the write fault reset signal. This signal is used to clear a write fault indication within the drive. On mini-sized drives, this bit can be used to turn on or off the drive motor prior to initiating a drive operation. A time delay after turn on may be necessary for the drive to come up to speed. The register must be read prior to writing the register in order to save the states of the remaining bits. When the register is subsequently written to modify bit 5, the remaining bits must be restored to their previous states.

IBM DISKETTE GENERAL FORMAT INFORMATION

The IBM Flexible Diskette used for data storage and retrieval is organized into concentric circular paths or TRACKS. There are 77 tracks on either one or both sides (surfaces) of the diskette. On double-sided diskettes, the corresponding top and bottom tracks are referred to as a CYLINDER. Each track is further divided into fixed length sections or SECTORS. The number of sectors per track — 26, 15 or 8 — is determined when a track is formatted and is dependent on the sector length — 128, 256 or 512 bytes respectively — specified.

All tracks on the diskette are referenced to a physical index mark (a small hole in the diskette). Each time the hole passes a photodetector cell (one revolution of the diskette), an Index pulse is generated to indicate the logical beginning of a track. This index pulse is used to initiate a track formatting operation.

Track Format

Each Diskette Surface is divided into 77 tracks with each track divided into fixed length sectors. A sector can hold a whole record or a part of a record. If the record is shorter than the sector length, the unused bytes are filled with binary zeros. If a record is longer than the sector length, the record is written over as many sectors as its length requires. The sector size that provides the most efficient use of diskette space can be chosen depending upon the record length required.

Tracks are numbered from 00 (outer-most) to 76 (inner-most) and are used as follows:

TRACK 00 reserved as System Label Track
TRACKS 01 through 74 used for data
TRACKS 75 and 76 used as alternates.

Each sector consists of an ID field (which holds a unique address for the sector) and a data field.

The ID field is seven bytes long and is written for each sector when the track is formatted. Each ID field consists of an ID field Address Mark, a Cylinder Number byte which identifies the track number, a Head Number byte which specifies the head used (top or bottom) to access the sector, a Record Number byte identifying the sector number (1 through 26 for 128 byte sectors), an N-byte specifying the byte length of the sector and two CRC (Cyclic Redundancy Check) bytes.

The Gaps separating the index mark and the ID and data fields are written on a track when it is formatted. These gaps provide both an interval for switching the drive electronics from reading or writing and compensation for rotational speed and other diskette-to-diskette and drive-to-drive manufacturing tolerances to ensure that data written on a diskette by one system can be read by another (diskette interchangeability).

IBM Format Implementation Summary

Track Format

The disk has 77 tracks, numbered physically from 00 to 76, with track 00 being the outermost track. There are logically 75 data tracks and two alternate tracks. Any two tracks may be initialized as bad tracks. The data tracks are numbered logically in sequence from 00 to 74, skipping over bad tracks (alternate tracks replace bad tracks). Note: In IBM format track 00 cannot be a bad track.

Sector Format

Each track is divided into 26, 15, or 8 sectors of 128, 256, or 512 bytes length respectively. The first sector is numbered 01, and is physically the first sector after the physical index mark. The logical sequence of the remaining sectors may be nonsequential physically. The location of these is determined at initialization by CPU software.

Each sector consists of an ID field and a data field. All fields are separated by gaps. The beginning of each field is indicated by 6 bytes of $(00)_H$ followed by a one byte address mark.

Address Marks

Address Marks are unique bit patterns one byte in length which are used to identify the beginning of ID and Data fields. Address Mark bytes are unique from all other data

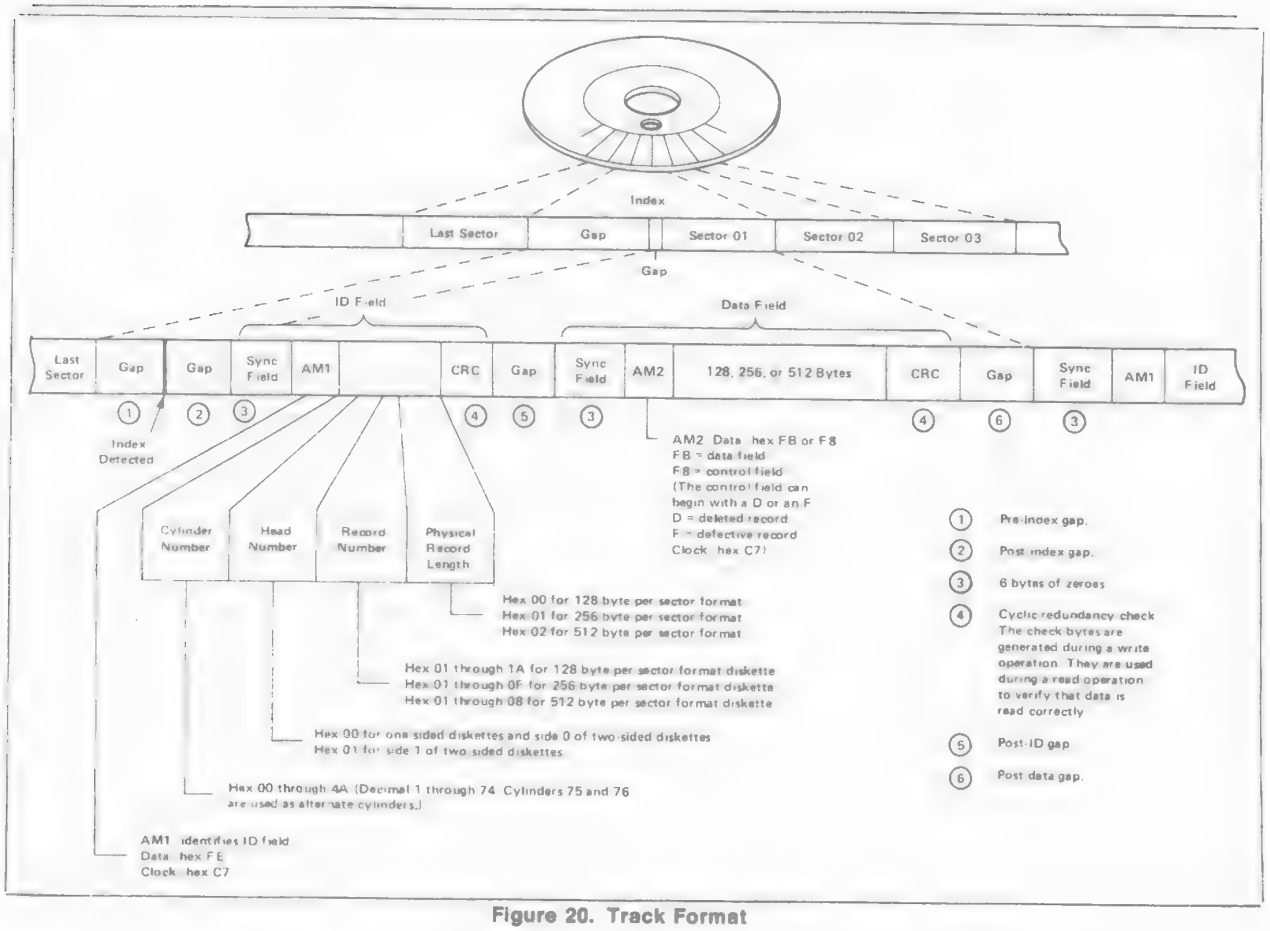


Figure 20. Track Format

bytes in that certain bit cells do not contain a clock bit (all other data bytes have clock bits in every bit cell.) There are four different types of Address Marks used. Each of these is used to identify different types of fields

Index Address Mark

The Index Address Mark is located at the beginning of each track and is a fixed number of bytes in front of the first record.

ID Address Mark

The ID Address Mark byte is located at the beginning of each ID field on the diskette.

Data Address Mark

The Data Address Mark byte is located at the beginning of each non-deleted Data Field on the diskette.

Deleted Data Address Mark

The Deleted Data Address Mark byte is located at the beginning of each deleted Data Field on the diskette.

Address Mark Summary	Clock Pattern	Data Pattern
Index Address Mark	D7	FC
ID Address Mark	C7	FE
Data Address Mark	C7	FB
Deleted Data Address Mark	C7	F8
Bad Track ID Address Mark	C7	FE

ID Field

MARK	C	H	R	N	CRC	CRC

C = Cylinder (Track) Address, 00-74
H = Head Address
R = Record (Sector) Address, 01-26
N = Record (Sector) Length, 00-02
Note: Sector Length = 128×2^N bytes
CRC = 16 Bit CRC Character (See Below)

Data Field

MARK	DATA	CRC	CRC

Data is 128, 256, or 512 bytes long.

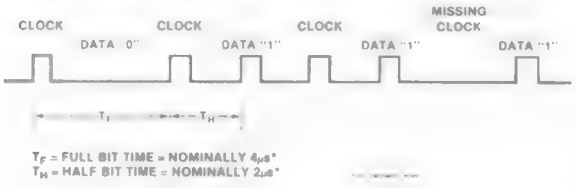
Note: All marks, data, ID characters and CRC characters are recorded and read most significant bit first.

CRC Character

The 16-bit CRC character is generated using the generator polynominal $X^{16} + X^{12} + X^5 + 1$, normally initialized to $(FF)_H$. It is generated from all characters (except the CRC in the ID or data field), including the data (not the clocks) in the address mark. It is recorded and read most significant bit first.

Data Format

Data is written (general case) in the following manner:



References

"The IBM Diskette for Standard Data Interchange," IBM Document GA21-9182-0. "System 32," Chapter 8, IBM Document GA21-9176-0.

Bad Track Format

The Bad Track Format is the same as the good track format except that the bad track ID field is initialized as follows:

$$C = H = R = N = (FF)_H$$

When formatting, bad track registers should be set to FF_H for the drive during the formatting, thus specifying no bad tracks. Thus, all tracks are left available for formatting.

The track following the bad track(s) should be one higher in number than track before the bad track(s).

Upon completion of the format the bad tracks should be set up using the write special register command. The 8271 will then generate an extra step pulse to cross the bad track, locating a new track that now happens to be an extra track out.

Format Track

Format Command

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD	0	0	SEL 1	SEL 0	1	0	0	0	1	1
PAR	0	1	TRACK ADDRESS							
PAR	0	1	GAP 3 SIZE MINUS 6							
PAR	0	1	RECORD LENGTH			NO. OF SECTORS/TRACK				
PAR	0	1	GAP 5 SIZE MINUS 6							
PAR	0	1	GAP 1 SIZE MINUS 6							

The format command can be used to initialize a disk track compatible with the IBM 3740 format. A Shugart "IBM Type" mini-floppy format may also be generated.

The Format command can be used to initialize a diskette, one track at a time. When format command is used, the program must supply ID fields for each sector on the track. During command execution, the supplied ID fields (track head sector addresses and the sector length) are written sequentially on the diskette. The ID address marks originate from the 8271 and are written automatically as the first byte of each ID field. The CRC character is written in the last two bytes of the ID field and is derived from the data written in the first five bytes. During the formatting operation, the data field of each sector is filled with data pattern $(E5)_H$. The CRC, derived from the data pattern is also appended to the last byte.

1. The parameter 2 ($D_7 - D_5$) of the Format command specify record length, the bits are coded the same way as in the Read Data commands.
2. The programmable gap sizes (gap 3, gap 5, and gap 1) must be programmed such that the 6 bytes of zero (sync) are subtracted from the intended gap size i.e., if gap 1 is intended to be 16 bytes long, programmed length must be 16 – 6 = 10 bytes (of FF_H's).

Mini-Floppy Disk Format

The mini-floppy disk format differs from the standard disk format in the following ways:

1. Gap 5 and the Index Address mark have been eliminated.
2. There are fewer sectors/tracks.

GAPS

The following is the gap size and description summary:

Gap 1 Programmable
Gap 2 17 Bytes
Gap 3 Programmable
Gap 4 Variable
Gap 5 Programmable

The last six bytes of gaps 1,2,3 and 5 are $(00)_H$, all other bytes in the gaps are $(FF)_H$. The Gap 1,3 and 5 count specified by the user are the number of bytes of $(FF)_H$. Gap 4 is written until the leading edge of the index pulse. If a Gap 5 size of zero is specified, the Index Mark is not written.

Gap 1: N bytes FF's 6 bytes 0's for sync	This gap separates the index address mark of the index pulse from the first ID mark. It is used to protect the first ID field from a write on the last physical sector of the current track.
Gap 2: 11 bytes FF's 6 bytes 0's for sync	This gap separates the ID field from the data mark and field such that during a write only the data field will be changed even if the write gate turns on early, due to drive speed changes.
Gap 3: N bytes FF's 6 bytes 0's for sync	This gap separates a data area from the next ID field. It is used so that during drive speed changes the next ID mark will not be overwritten, thus causing loss of data.
Gap 4: FF's only	This gap fills out the rest of the disk and is used for slack during formatting. During drive speed variations this gap will shrink or grow if the disk is re-formatted.
Gap 5: N bytes FF's 6 bytes 0's for sync	This gap separates the last sector from the Index Address mark and is used to assure that the index address mark is not destroyed by writing on the last physical data sector on the track.

The number of FF bytes is programmable for gaps 1, 3 and 5.

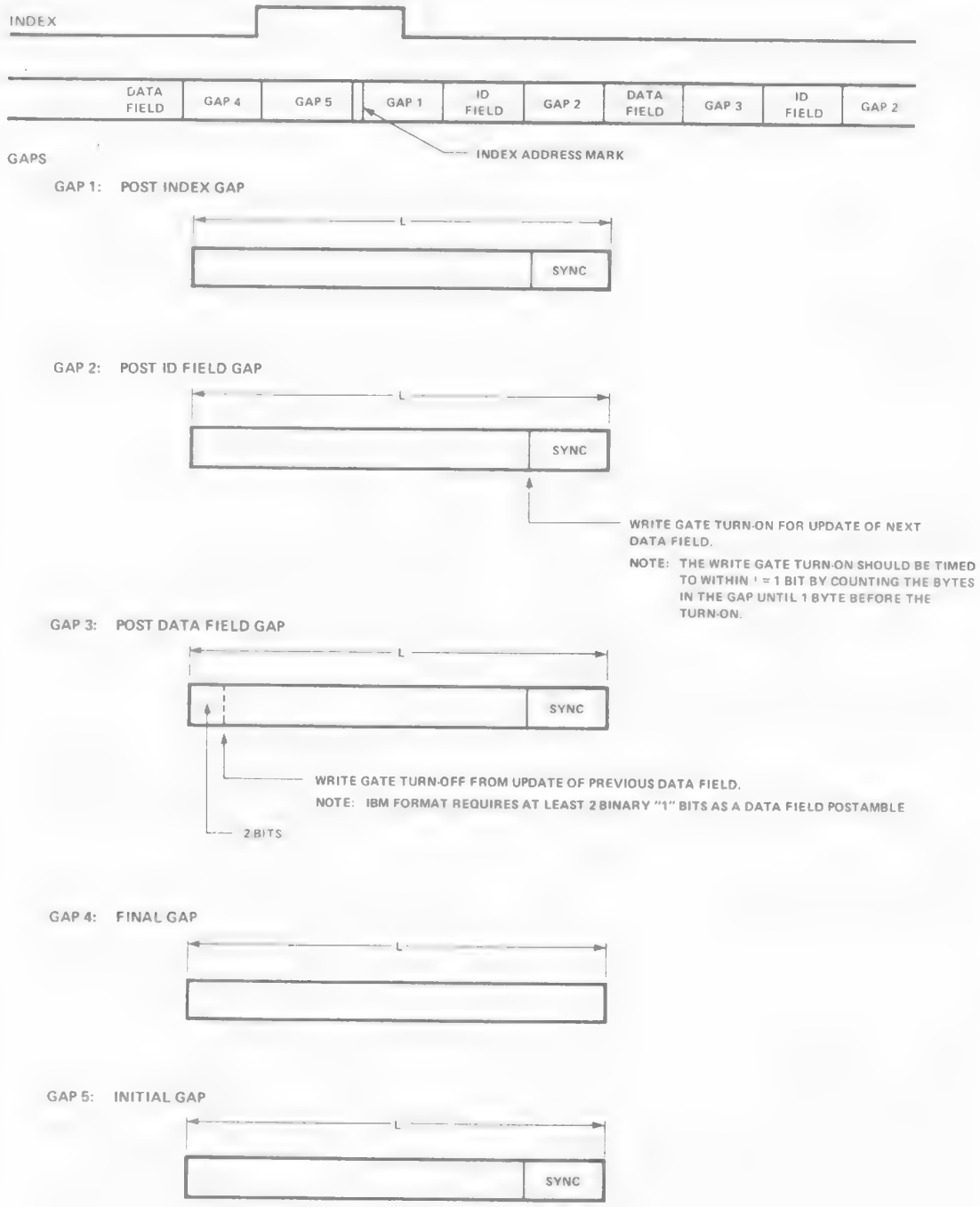
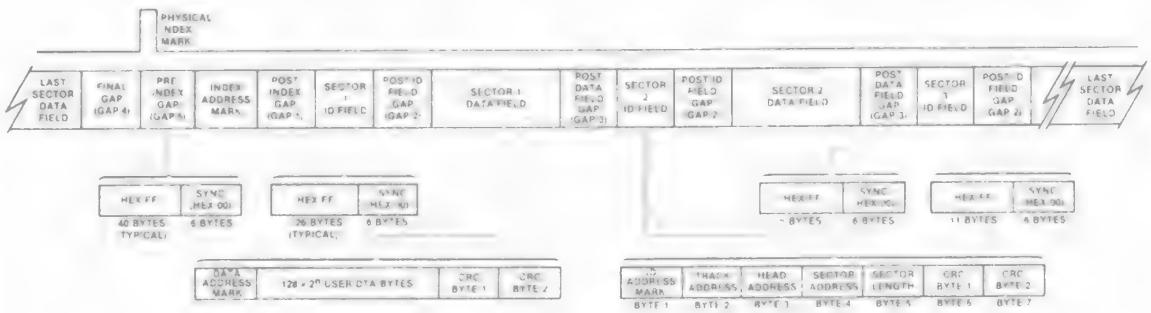


Figure 21. Track Format

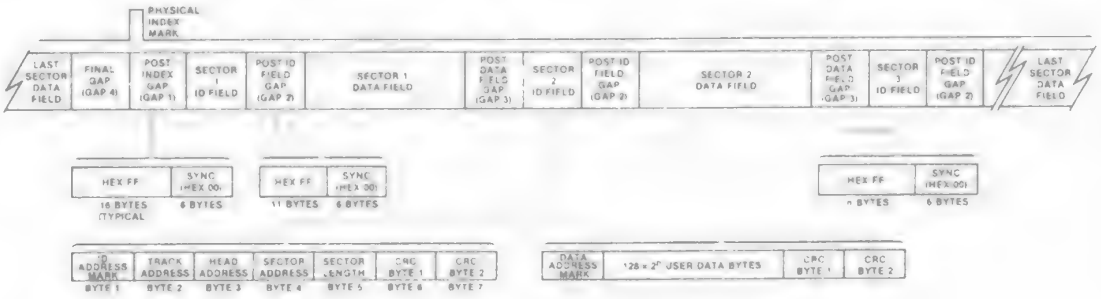


NUMBER OF SECTORS	NUMBER OF BYTES									
	GAP 1		ID FIELD	GAP 2		DATA FIELD	GAP 3		GAP 4	GAP 5	
	*ONES	SYNC		ONES	SYNC		*ONES	SYNC		*ONES	SYNC
26	26	6	7	11	6	131	27	6	275	40	6
15	26	6	7	11	6	259	48	6	129	40	6
8	26	6	7	11	6	515	90	6	146	40	6
4	26	6	7	11	6	1027	224	6	236	40	6
2	26	6	7	11	6	2051	255	6	719	40	6
1	26	6	7	11	6	4099	0	0	1007	40	6

*Program Specified

5208 Bytes Per Track

Figure 22. Standard Diskette Track Format



NUMBER OF SECTORS	NUMBER OF BYTES								
	GAP 1		ID FIELD	GAP 2		DATA FIELD	GAP 3		GAP 4
	*ONES	SYNC		ONES	SYNC		*ONES	SYNC	
18	16	6	7	11	6	131	11	6	24
10	16	6	7	11	6	259	21	6	30
5	16	6	7	11	6	515	74	6	88
2	16	6	7	11	6	1027	255	6	740
1	16	6	7	11	6	2051	0	0	1028

*Program Specified

3125 Bytes Per Track

Figure 23. Mini-Diskette Track Format

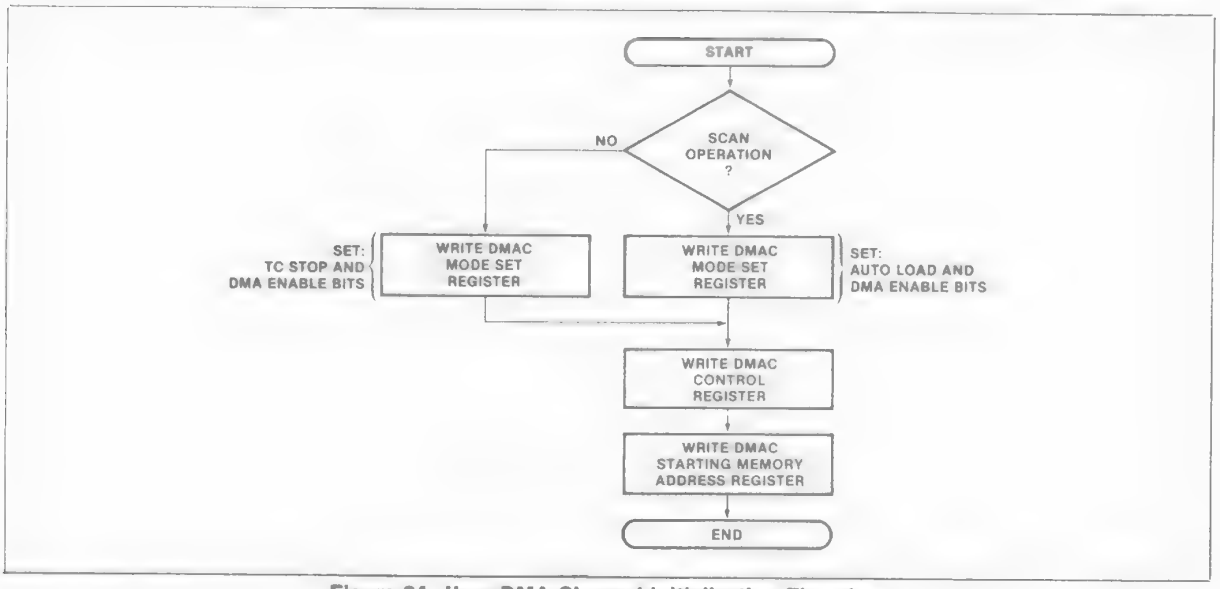


Figure 24. User DMA Channel Initialization Flowchart

Read ID Command

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD	0	0	SEL 1	SEL 0	0	1	1	0	1	1
PAR	0	1	TRACK ADDRESS							
PAR	0	1	0	0	0	0	0	0	0	0
PAR	0	1	NUMBER OF ID FIELDS							

The Read ID command transfers the specified number of ID fields into memory (beginning with the first ID field after Index). The CRC character is checked but not transferred.

These fields are entered into memory in the order in which they are physically located on the disk, with the first field being the one starting at the index pulse.

Data Processing Commands

All the routine Read/Write commands examine specific drive status lines before beginning execution, perform an implicit seek to the track address and load the drive's read/write head. Regardless of the type of command (i.e., read, write or verify), the 8271 first reads the ID field(s) to verify that the correct track has been located (see sector not found completion code) and also to locate the addressed sector. When a transfer is complete (or cannot be completed), the 8271 sets the interrupt request bit in the status register and provides an indication of the outcome of the operation in the result register.

If a CRC error is detected during a multisector transfer, processing is terminated with the sector in error. The address of the failing sector number can be determined by examining the Scan Sector Number register using the Read Special Register command.

Full power of the multisector read/write commands can be realized by doing DMA transfer using Intel® 8257 DMA Controller. For example, in a 128 byte per sector multisector write command, the entire data block (containing 128 bytes times the number of sectors) can be located in a disk memory buffer. Upon completion of the command phase, the 8271 begins execution by accessing the desired track, verifying the ID field, and locating the data field of the first record to be written. The 8271 then DMA-accesses the first sector and starts counting and writing one byte at a time until all 128 bytes are written. It then locates the data field of the next sector and repeats the procedure until all the specified sectors have been written. Upon completion of the execution phase the 8271 enters into the result phase and interrupts the CPU for availability of status and completion results. Note that all read/write commands, single or multisector are executed without CPU intervention.

Note, execution of multi-sector operations are faster if the sectors are *not* interleaved.

128 Byte Single Record Format

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD	0	0	SEL 1	SEL 0	COMMAND OPCODE					
PAR	0	1	TRACK ADDR 0 255							
PAR	0	1	SECTOR 0 255							

Commands	Opcode
READ DATA	12
READ DATA AND DELETED DATA	16
WRITE DATA	0A
WRITE DELETED DATA	0E
VERIFY DATA AND DELETED DATA	1E

Variable Length/Multi-Record Format

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD	0	0	SEL 1	SEL 0	COMMAND OPCODE					
PAR	0	1	TRACK ADDR 0 255							
PAR	0	1	SECTOR 0 255							
PAR	0	1	LENGTH			NO. OF SECTORS				

D_7-D_5 of Parameter 2 determine the length of the disk record.

0 0 0	128 Bytes
0 0 1	256 Bytes
0 1 0	512 Bytes
0 1 1	1024 Bytes
1 0 0	2048 Bytes
1 0 1	4096 Bytes
1 1 0	8192 Bytes
1 1 1	16,384 Bytes

Commands	Opcode
READ DATA	13
READ DATA AND DELETED DATA	17
WRITE DATA	0B
WRITE DELETED DATA	0F
VERIFY DATA AND DELETED DATA	1F
SCAN DATA	00
SCAN DATA AND DELETED DATA	04

Read Commands

Read Data, Read Data and Deleted Data.

Function

The read command transfers data from a specified disk record or group of records to memory. The operation of this command is outlined in execution phase table.

Write Commands

Write Data, Write Deleted Data.

Function

The write command transfers data from memory to a specified disk record or group of records.

Verify Command

Verify Data and Deleted Data.

Function

The verify command is identical to the read data and deleted data command except that the data is not transferred to memory. This command is used to check that a record or a group of records has been written correctly by verifying the CRC character.

Scan Commands

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD	0	0	SEL 1	SEL 0	0	0	0	S DATA S DELD	0	0
PAR	0	1	TRACK ADDR 0 255							
PAR	0	1	SECTOR 0 255							
PAR	0	1	LENGTH			NO. OF SECTORS				
PAR	0	1	SCAN TYPE		STEP SIZE					
PAR	0	1	FIELD LENGTH (KEY)							

Command $D_2 = 0$ Scan Data
$D_2 = 1$ Scan Data and Deleted Data

Scan Commands, Scan Data and Scan Data and Deleted Data, are used to search a specific data pattern or "key" from memory. The 8271 FDC operation during a scan is unique in that data is read from memory and from the diskette simultaneously.

During the scan operation, the key is compared repetitively (using the 8257 DMA Controller in auto load mode) with the data read from the diskette (e.g., an eight byte key would be compared with the first eight bytes (1-8) read from the diskette, the second eight bytes (9-16), the third eight bytes (17-24), etc.). The scan operation is concluded when the key is located or when the specified number of sectors have been searched without locating the key. When concluded, the 8271 FDC requests an interrupt. The program must then read the result register to determine if the scan was successful (if the key was located). If successful, several of the FDC's special registers can be examined (read special registers command) to determine more specific information relating to the scan (i.e., the sector number in which the key was located, and the number of bytes within the sector that were not compared when the key was located).

The 8271 does not do a sliding scan, it does a fixed block linear search. This means the key in memory is compared to an equal length block in a sector; when these blocks meet the scan conditions the scan will stop. Otherwise, the scan continues until all the sectors specified have been searched.

The following factors regarding key length must be considered when establishing a key in memory.

1. When searching multiple sectors, the length of the key must be evenly divisible into the sector length to prevent the key from being split at subsequent sector boundaries. Since the character FF_H is not compared, the key in memory can be padded to the required length using this character. For example, if the actual pattern compared on the diskette is twelve characters in length, the field length should be sixteen and four bytes of FF_H

would be appended to the key. Consequently, the last block of sixteen bytes compared within the first sector would end at the sector boundary and the first byte of the next sector would be compared with the first byte of the key. Splitting data over sector boundarys will not work properly since the FDC expects the start of key at each sector boundary.

2. Since the first byte of the key is compared with the first byte of the sector, when the pattern does not begin with the first byte of the sector, the key must be offset using the character FF_{16}. For example, if the first byte of a nine byte pattern begins on the fifth byte of the sector, four bytes of FF_{16} are prefixed to the key (and three bytes of FF_{16} are appended to the key to meet the length requirement) so that the first actual comparison begins on the fifth byte.

The Scan Commands require five parameters:

Parameter 0, Track Address

Specifies the track number containing the sectors to be scanned. Legal values range from 00_H to $4C_H$ (0 to 76) for a standard diskette and from 00_H to 22_H (0 to 34) for a mini-sized diskette.

Parameter 1, Sector Address

Specifies the first sector to be scanned. The number of sectors scanned is specified in parameter 2, and the order in which sectors are scanned is specified in parameter 3.

Parameter 2, Sector Length/Number of Sectors

The sector length field (bits 7-5) specifies the number of data bytes allocated to each sector (see parameter 2, routine read and write commands for field interpretation). The number of sectors field (bits 4-0) specifies the number of sectors to be scanned. The number specified ranges from one sector to the physical number of sectors on the track.

Parameter 3

D_7-D_6: Indicate scan type

00-EQ Scan for each character within the field length (key) equal to the corresponding character within the disk sector. The scan stops after the first equal condition is met.

01-GEQ Scan for each character within the disk sector greater than or equal to the corresponding character within the field length (key). The scan stops after the first greater than or equal condition is met.

10-LEQ Scan for each character within the disk sector less than or equal to the corresponding character within the field length (key). The scan stops after the first less than or equal condition is met.

D_5-D_0: Step Size: The Step Size field specifies the offset to the next sector in a multisector scan. In this case, the next sector address is generated by adding the Step Size to the current sector address.

Parameter 4, Field Length

Specifies the number of bytes to be compared (length of key). While the range of legal values is from 1 to 255, the field length specified should be evenly divisible into the sector length to prevent the key from being split at sector boundaries, if the multisector scan commands are used.

Scan Command Results

More detailed information about the completion of Scan Commands may be obtained by executing Read Special Register commands.

Read Special Register

Parameter (Hex)	Results
06	The sector number of the sector in which the specified scan data pattern was located.
14	MSB Count — The number of 128 byte blocks remaining to be compared in the current sector when the scan data pattern was located. This register is decremented with each 128 byte block read.
13	LSB Count — The number of bytes remaining to be compared in the current sector when the scan data pattern is located. This register is initialized to 128 and is decremented with each byte compared.

Upon a scan met condition, the equation below can be used to determine the last byte in the located pattern.

Pointer = sector length – ((Register 14H)*128 + (Register 13H))

8271 Scan Command Example

Assume there are only 2 records on track 0 with the following data:

Record 01: 01 02 03 04 05 06 07 08 000....00
Record 02: 01 02 AA 55 00 00 00 00 00

Command	Field Length [1]	Starting Sector #	# of Sectors	Key [2]	Completion Code [3]	Special Registers [4] R06	R14	R13	Comment
• SCAN EQ	2	1	1	01,02	SME	01	0	127D	Met in first field
SCAN EQ	2	1	1	02,03	SNM	X	X	X	Not met
SCAN EQ	2	1	1	FF [5],05	SNM	X	X	X	Not met with don't care
• SCAN EQ	2	1	1	FF[5],06	SME	01	0	123D	Met with don't care
• SCAN EQ	2	1	2	AA,55	SME	02	0	125D	Met in Record 02
• SCAN EQ	2	2	1	01,02	SME	02	0	127D	Starting sector ≠ 1
• SCAN EQ	4	1	1	05,06,07,08	SME	01	0	121D	Field, Key length = 4
• SCAN GEQ	4	1	1	05,06,07,08	SME	01	0	121D	GEQ-SME
• SCAN GEQ	4	1	1	05,04,07,08	SMNE	01	0	121D	GEQ-SMNE
• SCAN GEQ	4	1	2	00,03,AA,44 [6]	SNM	X	X	X	GEQ-SNM
• SCAN LEQ	4	1	1	01,03,FF,04	SMNE	01	0	125D	LEQ-SMNE
• SCAN LEQ	4	1	1	01,02,FF,04	SME	01	0	125D	LEQ-SME

NOTES:

1. Field Length — Each record is partitioned into a number of fields equal to the record size divided by the field length Note that the record size should be evenly divisable by the field length to insure proper operation of multi record scan. Also, maximum field length = 256 bytes.

2. Key — The key is a string of bytes located in the user system memory. The key length should equal the field length By programming the 8257 DMA Controller into the auto load mode, the key will be recursively read in by the chip (once per field).

3. Completion Code — Shows how Scan command was met or not met
   SNM — SCAN Not Met — 0 0 (also Good Complete)
   SME — SCAN Met Equal — 0 1
   SMNE — SCAN Met Not Equal — 1 0

4. Special Registers
   R06 — This register contains the record number where the scan was met.
   R14 — This register contains the MSB count and is decremented every 128 characters.

Length (ℓ) (D7-D5 of PAR 2)	Record Size	R14 = $2^{\ell} - 1$ (Initialize at Beginning of Record)
000	128 Bytes	0
001	256 Bytes	1
010	512 Bytes	3
011	1024 Bytes	7
⋮	⋮	⋮

   R13 — This register contains a modulo 128 LSB count which is initialized to 128 at beginning of each record. This count is decremented after each character is compared except for the last character in a pattern match situation.

5. The OFF_H character in the key is treated as a don't care character position.

6. The Scan comparison is done on a byte by byte basis. That is, byte 1 of each field is compared to byte 1 of the key, byte 2 of each field is compared to byte 2 of the key, etc.

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias . . . . . 0°C to 70°C[1]
Storage Temperature . . . . . – 65°C to + 150°C
Voltage on Any Pin with
Respect to Ground . . . . . – 0.5V to + 7V
Power Dissipation . . . . . 1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (V_{CC} = + 5.0V ± 5%

8721 and 8271-8: T_A = 0°C to 70°C; 8271-6: T_A = 0°C to 50°C)

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_{IL}	Input Low Voltage	– 0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	(V_{CC} + 0.5)	V	
V_{OLD}	Output Low Voltage (Data Bus)		0.45	V	I_{OL} = 2.0 mA
V_{OLI}	Output Low Voltage (Interface Pins)		0.5	V	I_{OL} = 1.6 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = – 220 μA
I_{IL}	Input Load Current		± 10	μA	V_{IN} = V_{CC} to 0V
I_{OZ}	Off-State Output Current		± 10	μA	V_{OUT} = V_{CC} to 0.45V
I_{CC}	V_{CC} Supply Current		180	mA	

CAPACITANCE (T_A = 25°C; V_{CC} = GND = 0V)

Symbol	Parameter	Min.	Typ.	Max.	Unit	Test Conditions
C_N	Input Capacitance			10	pF	t_c = 1 MHz
$C_{I/O}$	I/O Capacitance			20	pF	Unmeasured Pins Returned to GND

NOTE: 1. Ambient temperature under bias for 8271-6 is 0°C to 50°C.

A.C. CHARACTERISTICS (V_{CC} = +5.0V ±5%)

(8271 and 8271-8: T_A = 0°C to 70°C; 8271-6: T_A = 0°C to 50°C)

READ CYCLE

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AC}	Select Setup to $\overline{RD}$	0		ns	Note 2
t_{CA}	Select Hold from $\overline{RD}$	0		ns	Note 2
t_{RR}	$\overline{RD}$ Pulse Width	250		ns	
t_{AD}	Data Delay from Address		250	ns	Note 2
t_{RD}	Data Delay from $\overline{RD}$		150	ns	C_L = 150 pF, Note 2
t_{DF}	Output Float Delay	20	100	ns	C_L = 20 pF for Minimum; 150 pF for Maximum
t_{DC}	DACK Setup to $\overline{RD}$	25		ns	
t_{CD}	DACK Hold from $\overline{RD}$	25		ns	
t_{KD}	Data Delay from DACK		250	ns	

A.C. CHARACTERISTICS (Continued)

WRITE CYCLE

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AC}	Select Setup to $\overline{WR}$	0		ns	
t_{CA}	Select Hold from $\overline{WR}$	0		ns	
t_{WW}	$\overline{WR}$ Pulse Width	250		ns	
t_{DW}	Data Setup to $\overline{WR}$	150		ns	
t_{WD}	Data Hold from $\overline{WR}$	0		ns	
t_{DC}	DACK Setup to $\overline{WR}$	25		ns	
t_{CD}	DACK Hold from $\overline{WR}$	25		ns	

DMA

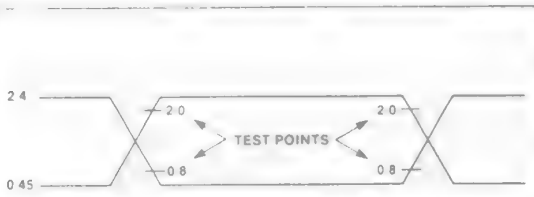
Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{CQ}	Request Hold from $\overline{WR}$ or $\overline{RD}$ (for Non-Burst Mode)		150	ns	

OTHER TIMINGS

Symbol	Parameter	8271/8271-6		Unit	Test Conditions
		Min.	Max.		
t_{RSTW}	Reset Pulse Width	10		t_{CY}	
t_r	Input Signal Rise Time		20	ns	
t_f	Input Signal Fall Time		20	ns	
t_{RSTS}	Reset to First IOWR	[illegible]		t_{CY}	
t_{CY}	Clock Period	250			Note 3
t_{CL}	Clock Low Period	110		ns	
t_{CH}	Clock High Period	125		ns	
t_{DS}	Data Window Setup to Unseparated Clock and Data	50		ns	
t_{DH}	Data Window Hold from Unseparated Clock and Data	0		ns	

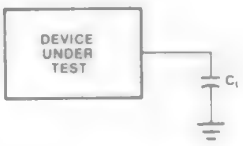
NOTES:
1. All timing measurements are made at the reference voltages unless otherwise specified: Input "1" at 2.0V, "0" at 0.8V
Output "1" at 2.0V, "0" at 0.8V
2. t_{AD}, t_{RD}, t_{AC}, and t_{CA} are not concurrent specs.
3. Standard Floppy: $t_{CY} = 250$ ns $\pm 0.4\%$ Mini-Floppy: $t_{CY} = 500$ ns $\pm 0.4\%$

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING: INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0". TIMING MEASUREMENTS ARE MADE AT 2.0V FOR A LOGIC "1" AND 0.8V FOR A LOGIC "0".

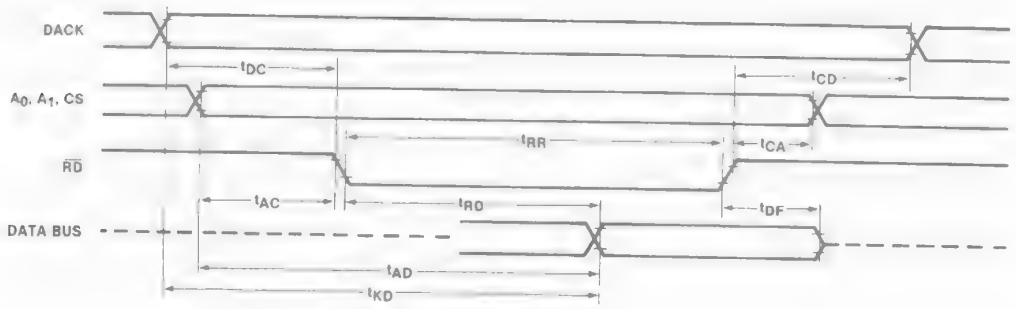
A.C. TESTING LOAD CIRCUIT



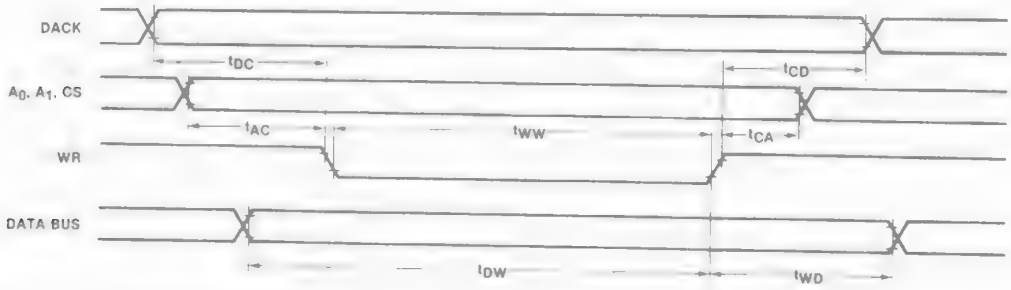
C_L INCLUDES JIG CAPACITANCE

WAVEFORMS

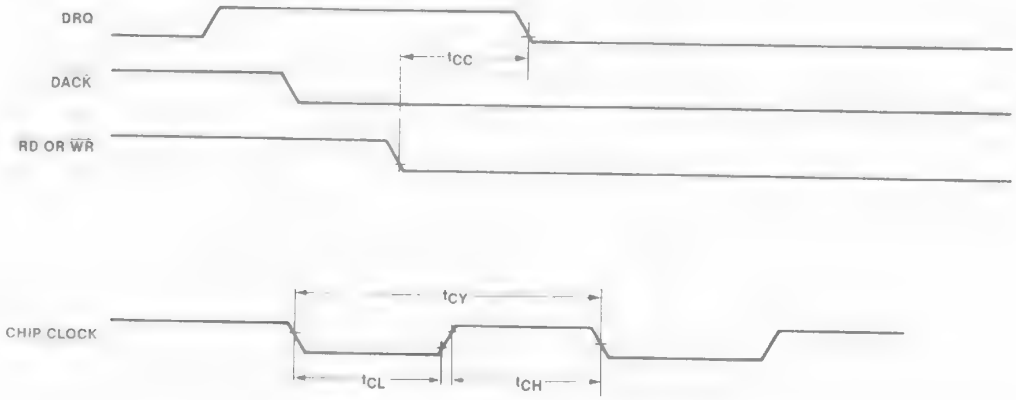
READ



WRITE



DMA



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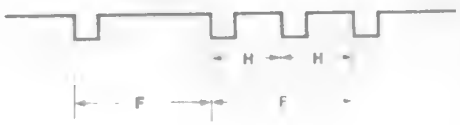
WAVEFORMS (Continued)

READ DATA



*t_{CY} = 250 ns **t_{CY} = 500 ns

F = 16 t_{CY} ± 8 t_{CY}
H = 8 t_{CY} ± 4 t_{CY}

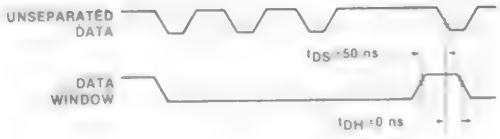
*STANDARD FLEXIBLE DISK DRIVE TIMING
**MINI-FLOPPY TIMING

WRITE DATA

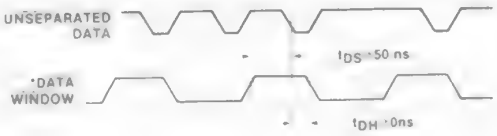
PULSE WIDTH PW = t_{CY} ± 30 ns
H (HALF BIT CELL) = 8 t_{CY}
F (FULL BIT CELL) = 16 t_{CY}

*t_{CY} =		**t_{CY} =	
250 ns	± 0.4%	500 ns	± 0.4%
250 ns	± 30 ns	500 ns	± 30 ns
2.0 µs	± 8 ns	4.0 µs	± 16 ns
4.0 µs	± 16 ns	8.0 µs	± 32 ns

SINGLE-SHOT DATA SEPARATOR



PLO DATA SEPARATOR



*DATA WINDOW MAY BE 180° OUT OF PHASE IN PLO DATA SEPARATION MODE

AFN-00223B

PRELIMINARY

8272A
SINGLE/DOUBLE DENSITY FLOPPY DISK CONTROLLER

- **IBM Compatible in Both Single and Double Density Recording Formats**
- **Programmable Data Record Lengths: 128, 256, 512, or 1024 Bytes/Sector**
- **Multi-Sector and Multi-Track Transfer Capability**
- **Drives Up to 4 Floppy or Mini-Floppy Disks**
- **Data Transfers in DMA or Non-DMA Mode**
- **Parallel Seek Operations on Up to Four Drives**
- **Compatible with all Intel and Most Other Microprocessors**
- **Single-Phase 8 MHz Clock**
- **Single +5 Volt Power Supply (±10%)**

The 8272A is an LSI Floppy Disk Controller (FDC) Chip, which contains the circuitry and control functions for interfacing a processor to 4 Floppy Disk Drives. It is capable of supporting either IBM 3740 single density format (FM), or IBM System 34 Double Density format (MFM) including double sided recording. The 8272A provides control signals which simplify the design of an external phase locked loop and write precompensation circuitry. The FDC simplifies and handles most of the burdens associated with implementing a Floppy Disk Drive Interface. The 8272A is a pin-compatible upgrade to the 8272.

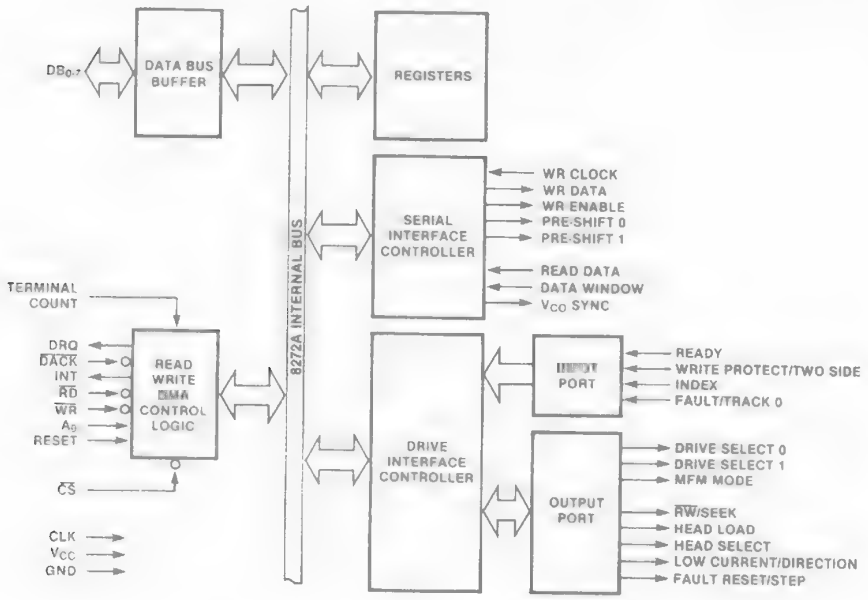


Figure 1. 8272A Internal Block Diagram

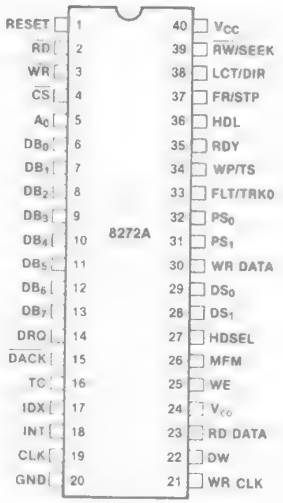


Figure 2. Pin Configuration

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ORDER NUMBER 210606-001

Table 1. Pin Description

Symbol	Pin No.	Type	Connection To	Name and Function
RESET	1	I	μP	**Reset:** Places FDC in idle state. Resets output lines to FDD to "0" (low). Does not clear the last specify command.
$\overline{RD}$	2	I[1]	μP	**Read:** Control signal for transfer of data from FDC to Data Bus, when "0" (low).
$\overline{WR}$	3	I[1]	μP	**Write:** Control signal for transfer of data to FDC via Data Bus, when "0" (low).
$\overline{CS}$	4	I	μP	**Chip Select:** IC selected when "0" (low), allowing $\overline{RD}$ and $\overline{WR}$ to be enabled.
A_0	5	I[1]	μP	**Data/Status Register Select:** Selects Data Reg (A_0 = 1) or Status Reg (A_0 = 0) contents to be sent to Data Bus.
DB_0-DB_7	6–13	I/O[1]	μP	**Data Bus:** Bidirectional 8-Bit Data Bus.
DRQ	14	O	DMA	**Data DMA Request:** DMA Request is being made by FDC when DRQ "1."
$\overline{DACK}$	15	I	DMA	**DMA Acknowledge:** DMA cycle is active when "0" (low) and Controller is performing DMA transfer.
TC	16	I	DMA	**Terminal Count:** Indicates the termination of a DMA transfer when "1" (high)[2].
IDX	17	I	FDD	**Index:** Indicates the beginning of a disk track.
INT	18	O	μP	**Interrupt:** Interrupt Request Generated by FDC
CLK	19	I		**Clock:** Single Phase 8 MHz (4 MHz for mini floppies) Squarewave Clock.
GND	20			**Ground:** D.C. Power Return.
V_{CC}	40			**D.C. Power:** +5V
$\overline{RW}$/SEEK	39	O	FDD	**Read Write / SEEK:** When "1" (high) Seek mode selected and when "0" (low) Read/Write mode selected.
LCT/DIR	38	O	FDD	**Low Current/Direction:** Lowers Write current on inner tracks in Read/Write mode, determines direction head will step in Seek mode.
FR/STP	37	O	FDD	**Fault Reset/Step:** Resets fault FF in FDD in Read/Write mode, provides step pulses to move head to another cylinder in Seek mode.
HDL	36	O	FDD	**Head Load:** Command which causes read/write head in FDD to contact diskette.
RDY	35	I	FDD	**Ready:** Indicates FDD is ready to send or receive data. Must be tied high (gated by the index pulse) for mini floppies which do not normally have a Ready line.
WP/TS	34	I	FDD	**Write Protect / Two-Side:** Senses Write Protect status in Read/Write mode, and Two Side Media in Seek mode.
FLT TRK0	33	I	FDD	**Fault/Track 0:** Senses FDD fault condition in Read/Write mode and Track 0 condition in Seek mode.
PS_1,PS_0	31,32	O	FDD	**Precompensation (preshift):** Write precompensation status during MFM mode. Determines early, late, and normal times
WR DATA	30	O	FDD	**Write Data:** Serial clock and data bits to FDD
DS_1,DS_0	28,29	O	FDD	**Drive Select:** Selects FDD unit
HDSEL	27	O	FDD	**Head Select:** Head 1 selected when "1" (high) Head 0 selected when "0" (low).

Note 1: Disabled when $\overline{CS}$=1
Note 2: TC must be activated to terminate the Execution Phase of any command

Table 1. Pin Description (Continued)

Symbol	Pin No.	Type	Connection To	Name and Function
MFM	26	O	PLL	**MFM Mode:** MFM mode when "1," FM mode when "0."
WE	25	O	FDD	**Write Enable:** Enables write data into FDD.
VCO	24	O	PLL	**VCO Sync:** Inhibits VCO in PLL when "0" (low), enables VCO when "1."
RD DATA	23	I	FDD	**Read Data:** Read data from FDD, containing clock and data bits.
DW	22	I	PLL	**Data Window:** Generated by PLL, and used to sample data from FDD.
WR CLK	21	I		**Write Clock:** Write data rate to FDD FM = 500 kHz, MFM = 1 MHz, with a pulse width of 250 ns for both FM and MFM. Must be enabled for all operations, both Read and Write.

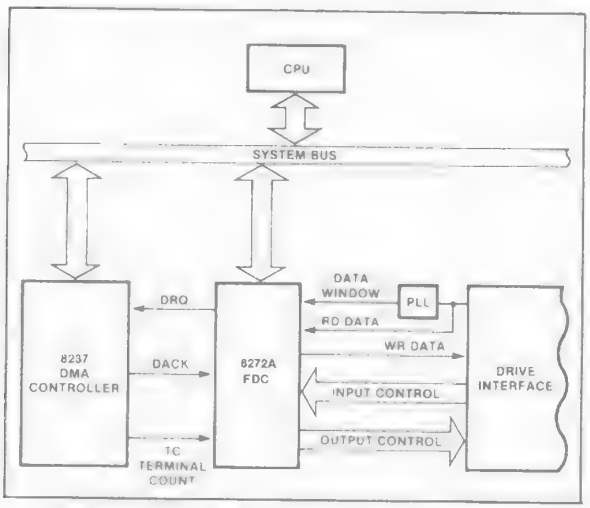


Figure 3. 8272A System Block Diagram

DESCRIPTION

Hand-shaking signals are provided in the 8272A which make DMA operation easy to incorporate with the aid of an external DMA Controller chip, such as the 8237A. The FDC will operate in either DMA or Non-DMA mode. In the Non-DMA mode, the FDC generates interrupts to the processor for every transfer of a data byte between the CPU and the 8272A. In the DMA mode, the processor need only load a command into the FDC and all data transfers occur under control of the 8272A and DMA controller.

There are 15 separate commands which the 8272A will execute. Each of these commands require multiple 8-bit bytes to fully specify the operation which the processor wishes the FDC to perform. The following commands are available.

Read Data	Write Data
Read ID	Format a Track
Read Deleted Data	Write Deleted Data
Read a Track	Seek
Scan Equal	Recalibrate (Restore to Track 0)
Scan High or Equal	Sense Interrupt Status
Scan Low or Equal	Sense Drive Status
Specify	

For more information see the Intel Application Notes AP-116 and AP-121.

FEATURES

Address mark detection circuitry is internal to the FDC which simplifies the phase locked loop and read electronics. The track stepping rate, head load time, and head unload time may be programmed by the user. The 8272A offers many additional features such as multiple sector transfers in both read and write modes with a single command, and full IBM compatibility in both single (FM) and double density (MFM) modes.

8272A ENHANCEMENTS

On the 8272A, after detecting the Index Pulse, the VCO Sync output stays low for a shorter period of time. See Figure 4A.

On the 8272 there can be a problem reading data when Gap 4A is 00 and there is no IAM. This occurs on some older floppy formats. The 8272A cures this problem by adjusting the VCO Sync timing so that it is not low during the data field. See Figure 4B.

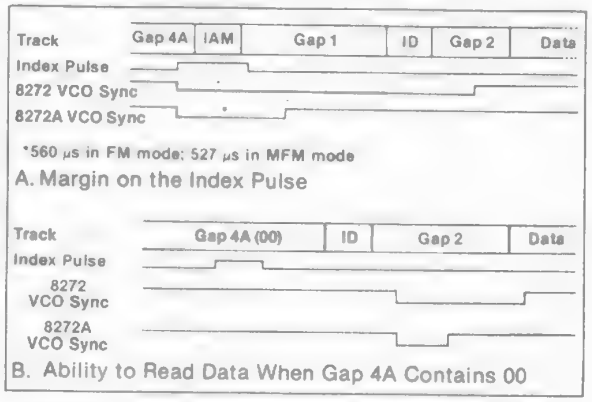


Figure 4. 8272A Enhancements over the 8272

8272A REGISTERS — CPU INTERFACE

The 8272A contains two registers which may be accessed by the main system processor; a Status Register and a Data Register. The 8-bit Main Status Register contains the status information of the FDC, and may be accessed at any time. The 8-bit Data Register (actually consists of several registers in a stack with only one register presented to the data bus at a time), stores data, commands, parameters, and FDD status information. Data bytes are read out of, or written into, the Data Register in order to program or obtain the results after execution of a command. The Status Register may only be read and is used to facilitate the transfer of data between the processor and 8272A.

The relationship between the Status/Data registers and the signals $\overline{RD}$, $\overline{WR}$, and A_0 is shown in Table 2.

Table 2. A_0, $\overline{RD}$, $\overline{WR}$ decoding for the selection of Status/Data register functions.

A_0	$\overline{RD}$	$\overline{WR}$	FUNCTION
0	0	1	Read Main Status Register
0	1	0	Illegal (see note)
0	0	0	Illegal (see note)
1	0	0	Illegal (see note)
1	0	1	Read from Data Register
1	1	1	Write into Data Register

Note: Design must guarantee that the 8272A is not subjected to illegal inputs.

The Main Status Register bits are defined in Table 3.

Table 3. Main Status Register bit description.

BIT NUMBER	NAME	SYMBOL	DESCRIPTION
D_0	FDD 0 Busy	D_0B	FDD number 0 is in the Seek mode.
D_1	FDD 1 Busy	D_1B	FDD number 1 is in the Seek mode
D_2	FDD 2 Busy	D_2B	FDD number 2 is in the Seek mode.
D_3	FDD 3 Busy	D_3B	FDD number 3 is in the Seek mode.
D_4	FDC Busy	CB	A read or write command is in process.
D_5	Non-DMA mode	NDM	The FDC is in the non-DMA mode. This bit is set only during the execution phase in non-DMA mode. Transition to "0" state indicates execution phase has ended.
D_6	Data Input/Output	DIO	Indicates direction of data transfer between FDC and Dta Register. If DIO = "1" then transfer is from Data Register to the Processor. If DIO = "0", then transfer is from the Processor to Data Register.
D_7	Request for Master	RQM	Indicates Data Register is ready to send or receive data to or from the Processor. Both bits DIO and RQM should be used to perform the handshaking functions of "ready" and "direction" to the processor.

The DIO and RQM bits in the Status Register indicate when Data is ready and in which direction data will be transferred on the Data Bus.

Note: There is a 12μS or 24μS RQM flag delay when using an 8 or 4 MHz clock respectively.

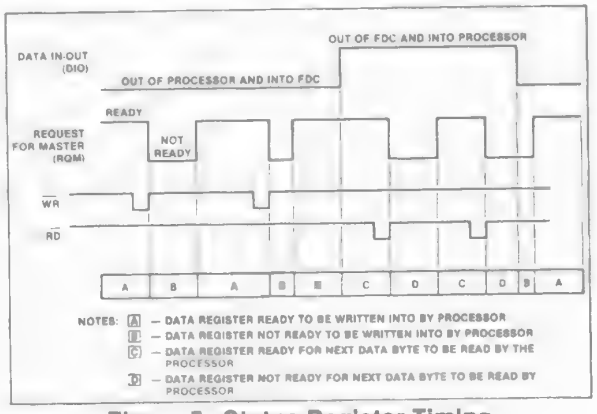


Figure 5. Status Register Timing

The 8272A is capable of executing 15 different commands. Each command is initiated by a multi-byte transfer from the processor, and the result after execution of the command may also be a multi-byte transfer back to the processor. Because of this multi-byte interchange of information between the 8272A and the processor, it is convenient to consider each command as consisting of three phases:

Command Phase: The FDC receives all information required to perform a particular operation from the processor.

Execution Phase: The FDC performs the operation it was instructed to do.

Result Phase: After completion of the operation, status and other housekeeping information are made available to the processor.

During Command or Result Phases the Main Status Register (described in Table 3) must be read by the processor before each byte of information is written into or read from the Data Register. Bits D6 and D7 in the Main Status Register must be in a 0 and 1 state, respectively, before each byte of the command word may be written into the 8272A. Many of the commands require multiple bytes, and as a result the Main Status Register must be read prior to each byte transfer to the 8272A. On the other hand, during the Result Phase, D6 and D7 in the Main Status Register must both be 1's (D6 = 1 and D7 = 1) before reading each byte from the Data Register. Note, this reading of the Main Status Register before each byte transfer to the 8272A is required in only the Command and Result Phases, and NOT during the Execution Phase.

During the Execution Phase, the Main Status Register need not be read. If the 8272A is in the non-DMA Mode, then the receipt of each data byte (if 8272A is reading data from FDD) is indicated by an Interrupt signal on pin 18 (INT = 1). The generation of a Read signal (RD = 0) will reset the Interrupt as well as output the Data onto

the Data Bus. For example, if the processor cannot handle Interrupts fast enough (every 13 μs for MFM mode) then it may poll the Main Status Register and then bit D7 (RQM) functions just like the Interrupt signal. If a Write Command is in process, then the WR signal performs the reset to the Interrupt signal.

The 8272A always operates in a multi-sector transfer mode. It continues to transfer data until the TC input is active. In Non-DMA Mode, the system must supply the TC input.

If the 8272A is in the DMA Mode, no Interrupts are generated during the Execution Phase. The 8272A generates DRQ's (DMA Requests) when each byte of data is available. The DMA Controller responds to this request with both a $\overline{DACK}=0$ (DMA Acknowledge) and a $\overline{RD}=0$ (Read signal). When the DMA Acknowledge signal goes low ($\overline{DACK}=0$) then the DMA Request is reset (DRQ = 0). If a Write Command has been programmed then a $\overline{WR}$ signal will appear instead of $\overline{RD}$. After the Execution Phase has been completed (Terminal Count has occurred) then an Interrupt will occur (INT = 1). This signifies the beginning of the Result Phase. When the first byte of data is read during the Result Phase, the Interrupt is automatically reset (INT = 0).

It is important to note that during the Result Phase all bytes shown in the Command Table must be read. The Read Data Command, for example, has seven bytes of data in the Result Phase. All seven bytes must be read in order to successfully complete the Read Data Command. The 8272A will not accept a new command until all seven bytes have been read. Other commands may require fewer bytes to be read during the Result Phase.

The 8272A contains five Status Registers. The Main Status Register mentioned above may be read by the processor at any time. The other four Status Registers (ST0, ST1, ST2, and ST3) are only available during the Result Phase, and may be read only after successfully completing a command. The particular command which has been executed determines how many of the Status Registers will be read.

The bytes of data which are sent to the 8272A to form the Command Phase, and are read out of the 8272A in the Result Phase, must occur in the order shown in the Table 4. That is, the Command Code must be sent first and the other bytes sent in the prescribed sequence. No foreshortening of the Command or Result Phases are allowed. After the last byte of data in the Command Phase is sent to the 8272A, the Execution Phase

Table 4. 8272A Command Set

PHASE	R/W	DATA BUS D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	REMARKS
READ DATA										
Command	W	MT	MFM	SK	0	0	1	1	0	Command Codes
	W	0	0	0	0	0	HDS	DS1	DS0	
	W				C					Sector ID information prior to Command execution
	W				H					
	W				R					
	W				N					
	W				EOT					
	W				GPL					
	W				DTL					
Execution										Data transfer between the FDD and main-system
Result	R				ST 0					Status information after Command execution
	R				ST 1					
	R				ST 2					
	R				C					Sector ID information after command execution
	R				H					
	R				R					
	R				N					
READ DELETED DATA										
Command	W	MT	MFM	SK	0	1	1	0	0	Command Codes
	W	0	0	0	0	0	HDS	DS1	DS0	
	W				C					Sector ID information prior to Command execution
	W				H					
	W				R					
	W				N					
	W				EOT					
	W				GPL					
	W				DTL					
Execution										Data transfer between the FDD and main-system
Result	R				ST 0					Status information after Command execution
	R				ST 1					
	R				ST 2					
	R				C					Sector ID information after Command execution
	R				H					
	R				R					
	R				N					

PHASE	R/W	DATA BUS D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	REMARKS
WRITE DATA										
Command	W	MT	MFM	0	0	0	1	0	1	Command Codes
	W	0	0	0	0	0	HDS	DS1	DS0	
	W				C					Sector ID information prior to Command execution
	W				H					
	W				R					
	W				N					
	W				EOT					
	W				GPL					
	W				DTL					
Execution										Data transfer between the main-system and FDD
Result	R				ST 0					Status information after Command execution
	R				ST 1					
	R				ST 2					
	R				C					Sector ID information after Command execution
	R				H					
	R				R					
	R				N					
WRITE DELETED DATA										
Command	W	MT	MFM	0	0	1	0	0	1	Command Codes
	W	0	0	0	0	0	HDS	DS1	DS0	
	W				C					Sector ID information prior to Command execution
	W				H					
	W				R					
	W				N					
	W				EOT					
	W				GPL					
	W				DTL					
Execution										Data transfer between the FDD and main-system
Result	R				ST 0					Status information after Command execution
	R				ST 1					
	R				ST 2					
	R				C					Sector ID information after Command execution
	R				H					
	R				R					
	R				N					

Note 1. Symbols used in this table are described at the end of this section.
2. $A_0 = 1$ for all operations
3. X = Don't care, usually made to equal binary 0.

Table 4. 8272A Command Set (Continued)

PHASE	R/W	DATA BUS D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	REMARKS
READ A TRACK										
Command	W	0	MFM	SK	0	0	0	1	0	Command Codes
	W	0	0	0	0	0	HDS	DS1	DS0	
	W	C								Sector ID information prior to Command execution
	W	H								
	W	R								
	W	N								
	W	EOT								
	W	GPL								
	W	DTL								
Execution										Data transfer between the FDD and main-system. FDC reads all of cylinders contents from index hole to EOT
Result	R	ST 0								Status information after Command execution
	R	ST 1								
	R	ST 2								
	R	C								Sector ID information after Command execution
	R	H								
	R	R								
	R	N								
READ ID										
Command	W	0	MFM	0	0	1	0	1	0	Commands
	W	0	0	0	0	0	HDS	DS1	DS0	
Execution										The first correct ID information on the Cylinder is stored in Data Register
Result	R	ST 0								Status information after Command execution
	R	ST 1								
	R	ST 2								
	R	C								Sector ID information during Execution Phase
	R	H								
	R	R								
	R	N								
FORMAT A TRACK										
Command	W	0	MFM	0	0	1	1	0	1	Command Codes
	W	0	0	0	0	0	HDS	DS1	DS0	
	W	N								Bytes/Sector
	W	SC								Sectors/Cylinder
	W	GPL								Gap 3
	W	D								Filler Byte
Execution										FDC formats an entire cylinder
Result	R	ST 0								Status information after Command execution
	R	ST 1								
	R	ST 2								
	R	C								In this case, the ID information has no meaning
	R	H								
	R	R								
	R	N								
SCAN EQUAL										
Command	W	MT	MFM	SK	1	0	0	0	1	Command Codes
	W	0	0	0	0	0	HDS	DS1	DS0	
	W	C								Sector ID information prior to Command execution
	W	H								
	W	R								
	W	N								
	W	EOT								
	W	GPL								
	W	STP								
Execution										Data compared between the FDD and main-system
Result	R	ST 0								Status information after Command execution
	R	ST 1								
	R	ST 2								
	R	C								Sector ID information after Command execution
	R	H								
	R	R								
	R	N								
SCAN LOW OR EQUAL										
Command	W	MT	MFM	SK	1	1	0	0	1	Command Codes
	W	0	0	0	0	0	HDS	DS1	DS0	
	W	C								Sector ID information prior Command execution
	W	H								
	W	R								
	W	N								
	W	EOT								
	W	GPL								
	W	STP								
Execution										Data compared between the FDD and main-system
Result	R	ST 0								Status information after Command execution
	R	ST 1								
	R	ST 2								
	R	C								Sector ID information after Command execution
	R	H								
	R	R								
	R	N								
SCAN HIGH OR EQUAL										
Command	W	MT	MFM	SK	1	1	1	0	1	Command Codes
	W	0	0	0	0	0	HDS	DS1	DS0	
	W	C								Sector ID information prior Command execution
	W	H								
	W	R								
	W	N								
	W	EOT								
	W	GPL								
	W	STP								
Execution										Data compared between the FDD and main-system
Result	R	ST 0								Status information after Command execution
	R	ST 1								
	R	ST 2								
	R	C								Sector ID information after Command execution
	R	H								
	R	R								
	R	N								
RECALIBRATE										
Command	W	0	0	0	0	0	1	1	1	Command Codes
	W	0	0	0	0	0	0	DS1	DS0	
Execution										Head retracted to Track 0
SENSE INTERRUPT STATUS										
Command	W	0	0	0	0	1	0	0	0	Command Codes
Result	R	ST 0								Status information at the end of each seek operation about the FDC
	R	PCN								
SPECIFY										
Command	W	0	0	0	0	0	0	1	1	Command Codes
	W	SRT					HUT			
	W	HLT							ND	
SENSE DRIVE STATUS										
Command	W	0	0	0	0	0	1	0	0	Command Codes
	W	0	0	0	0	0	HDS	DS1	DS0	
Result	R	ST 3								Status information about FDD
SEEK										
Command	W	0	0	0	0	1	1	1	1	Command Codes
	W	0	0	0	0	0	HDS	DS1	DS0	
	W	NCN								
Execution										Head is positioned over proper Cylinder on Diskette
INVALID										
Command	W	Invalid Codes								Invalid Command Codes (NoOp — FDC goes into Standby State)
Result	R	ST 0								ST 0 = 80 (16)

Table 5. Command Mneumonics

SYMBOL	NAME	DESCRIPTION
A_0	Address Line 0	A_0 controls selection of Main Status Register ($A_0 = 0$) or Data Register ($A_0 = 1$).
C	Cylinder Number	C stands for the current selected Cylinder track number 0 through 76 of the medium.
D	Data	D stands for the data pattern which is going to be written into a Sector.
D_7–D_0	Data Bus	8-bit Data Bus where D_7 is the most significant bit, and D_0 is the least significant bit
DS0, DS1	Drive Select	DS stands for a selected drive number 0 or 1
DTL	Data Length	When N is defined as 00, DTL stands for the data length which users are going to read out or write into the Sector.
EOT	End of Track	EOT stands for the final Sector number of a Cylinder.
GPL	Gap Length	GPL stands for the length of Gap 3 (spacing between Sectors excluding VCO Sync Field).
H	Head Address	H stands for head number 0 or 1, as specified in ID field.
HDS	Head Select	HDS stands for a selected head number 0 or 1 (H = HDS in all command words)
HLT	Head Load Time	HLT stands for the head load time in the FDD (2 to 254 ms in 2 ms increments).
HUT	Head Unload Time	HUT stands for the head unload time after a read or write operation has occurred (16 to 240 ms in 16 ms increments).
MFM	FM or MFM Mode	If MF is low, FM mode is selected and if it is high, MFM mode is selected.
MT	Multi-Track	If MT is high, a multi-track operation is to be performed (a cylinder under both HD0 and HD1 will be read or written).
N	Number	N stands for the number of data bytes written in a Sector.
NCN	New Cylinder Number	NCN stands for a new Cylinder number, which is going to be reached as a result of the Seek operation. Desired position of Head.
ND	Non-DMA Mode	ND stands for operation in the Non-DMA Mode
PCN	Present Cylinder Number	PCN stands for the Cylinder number at the completion of SENSE INTERRUPT STATUS Command. Position of Head at present time
R	Record	R stands for the Sector number, which will be read or written.
R/W	Read/Write	R/W stands for either Read (R) or Write (W) signal.
SC	Sector	SC indicates the number of Sectors per Cylinder.
SK	Skip	SK stands for Skip Deleted Data Address Mark
SRT	Step Rate Time	SRT stands for the Stepping Rate for the FDD (1 to 16 ms in 1 ms increments). The same Stepping Rate applies to all drives (F = 1 ms, E = 2 ms, etc.).
ST 0 ST 1 ST 2 ST 3	Status 0 Status 1 Status 2 Status 3	ST 0–3 stand for one of four registers which store the status information after a command has been executed. This information is available during the result phase after command execution. These registers should not be confused with the main status register (selected by $A_0 = 0$). ST 0–3 may be read only after a command has been executed and contain information relevant to that particular command
STP		During a Scan operation, if STP = 1, the data in contiguous sectors is compared byte by byte with data sent from the processor (or DMA), and if STP = 2, then alternate sectors are read and compared.

automatically starts. In a similar fashion, when the last byte of data is read out in the Result Phase, the command is automatically ended and the 8272A is ready for a new command. A command may be aborted by simply sending a Terminal Count signal to pin 16 (TC = 1). This is a convenient means of ensuring that the processor may always get the 8272A's attention even if the disk system hangs up in an abnormal manner.

POLLING FEATURE OF THE 8272A

After power-up RESET, the Drive Select Lines DS0 and DS1 will automatically go into a polling mode. In between commands (and between step pulses in the SEEK command) the 8272A polls all four FDDs looking for a change in the Ready line from any of the drives. If the Ready line changes state (usually due to a door opening or closing) then the 8272A will generate an interrupt. When Status Register 0 (ST0) is read (after Sense Interrupt Status is issued), Not Ready (NR) will be indicated. The polling of the Ready line by the 8272A occurs continuously between instructions, thus notifying the processor which drives are on or off line. Approximate scan timing is shown in Table 6.

Table 6. Scan Timing

DS1	DS0	APPROXIMATE SCAN TIMING
0	0	220μS
0	1	220μS
1	0	220μS
1	1	440μS

COMMAND DESCRIPTIONS

During the Command Phase, the Main Status Register must be polled by the CPU before each byte is written into the Data Register. The DIO (DB6) and RQM (DB7) bits in the Main Status Register must be in the "0" and "1" states respectively, before each byte of the command may be written into the 8272A. The beginning of the execution phase for any of these commands will cause DIO and RQM to switch to "1" and "0" states respectively.

READ DATA

A set of nine (9) byte words are required to place the FDC into the Read Data Mode. After the Read Data command has been issued the FDC loads the head (if it is in the unloaded state), waits the specified head settling time (defined in the Specify Command), and begins reading ID Address Marks and ID fields. When the current sector number ("R") stored in the ID Register (IDR) compares with the sector number read off the diskette, then the FDC outputs data (from the data field) byte-by-byte to the main system via the data bus.

After completion of the read operation from the current sector, the Sector Number is incremented by one, and the data from the next sector is read and output on the data bus. This continuous read function is called a "Multi-Sector Read Operation." The Read Data Command must be terminated by the receipt of a Terminal Count signal. Upon receipt of this signal, the FDC stops outputting data to the processor, but will continue to read data from the current sector, check CRC (Cyclic Redundancy Count) bytes, and then at the end of the sector terminate the Read Data Command.

The amount of data which can be handled with a single command to the FDC depends upon MT (multi-track), MFM (MFM/FM), and N (Number of Bytes/Sector). Table 7 on the next page shows the Transfer Capacity.

Table 7. Transfer Capacity

Multi-Track MT	MFM/FM MFM	Bytes/Sector N	Maximum Transfer Capacity (Bytes/Sector) (Number of Sectors)	Final Sector Read from Diskette
0 0	0 1	00 01	(128) (26) = 3,328 (256) (26) = 6,656	26 at Side 0 or 26 at Side 1
1 1	0 1	00 01	(128) (52) = 6,656 (256) (52) = 13,312	26 at Side 1
0 0	0 1	01 02	(256) (15) = 3,840 (512) (15) = 7,680	15 at Side 0 or 15 at Side 1
1 1	0 1	01 02	(256) (30) = 7,680 (512) (30) = 15,360	15 at Side 1
0 0	0 1	02 03	(512) (8) = 4,096 (1024) (8) = 8,192	8 at Side 0 or 8 at Side 1
1 1	0 1	02 03	(512) (16) = 8,192 (1024) (16) = 16,384	8 at Side 1

The "multi-track" function (MT) allows the FDC to read data from both sides of the diskette. For a particular cylinder, data will be transferred starting at Sector 1, Side 0 and completing at Sector L, Side 1 (Sector L = last sector on the side). Note, this function pertains to only one cylinder (the same track) on each side of the diskette.

When N = 0, then DTL defines the data length which the FDC must treat as a sector. If DTL is smaller than the actual data length in a Sector, the data beyond DTL in the Sector is not sent to the Data Bus. The FDC reads (internally) the complete Sector performing the CRC check, and depending upon the manner of command termination, may perform a Multi-Sector Read Operation. When N is non-zero, then DTL has no meaning and should be set to 0FFH.

At the completion of the Read Data Command, the head is not unloaded until after Head Unload Time Interval (specified in the Specify Command) has elapsed. If the processor issues another command before the head unloads then the head settling time may be saved between subsequent reads. This time out is particularly valuable when a diskette is copied from one drive to another.

If the FDC detects the Index Hole twice without finding the right sector, (indicated in "R"), then the FDC sets the ND (No Data) flag in Status Register 1 to a 1 (high), and terminates the Read Data Command. (Status Register 0 also has bits 7 and 6 set to 0 and 1 respectively.)

After reading the ID and Data Fields in each sector, the FDC checks the CRC bytes. If a read error is detected (incorrect CRC in ID field), the FDC sets the DE (Data Error) flag in Status Register 1 to a 1 (high), and if a CRC error occurs in the Data Field the FDC also sets the DD (Data Error in Data Field) flag in Status Register 2 to a 1 (high), and terminates the Read Data Command. (Status Register 0 also has bits 7 and 6 set to 0 and 1 respectively.)

If the FDC reads a Deleted Data Address Mark off the diskette, and the SK bit (bit D5 in the first Command Word) is not set (SK = 0), then the FDC sets the CM (Control Mark) flag in Status Register 2 to a 1 (high), and terminates the Read Data Command, after reading all the data in the Sector. If SK = 1, the FDC skips the sector with the Deleted Data Address Mark and reads the next sector.

During disk data transfers between the FDC and the processor, via the data bus, the FDC must be serviced by the processor every 27 μs in the FM Mode, and every 13 μs in the MFM Mode, or the FDC sets the OR (Over Run) flag in Status Register 1 to a 1 (high), and terminates the Read Data Command.

If the processor terminates a read (or write) operation in the FDC, then the ID Information in the Result Phase is dependent upon the state of the MT bit and EOT byte. Table 5 shows the values for C, H, R, and N, when the processor terminates the Command.

Table 8. ID Information When Processor Terminates Command

MT	EOT	Final Sector Transferred to Processor	ID Information at Result Phase C	H	R	N
0	1A 0F 08	Sector 1 to 25 at Side 0 Sector 1 to 14 at Side 0 Sector 1 to 7 at Side 0	NC	NC	R + 1	NC
	1A 0F 08	Sector 26 at Side 0 Sector 15 at Side 0 Sector 8 at Side 0	C + 1	NC	R = 01	NC
	1A 0F 08	Sector 1 to 25 at Side 1 Sector 1 to 14 at Side 1 Sector 1 to 7 at Side 1	NC	NC	R + 1	NC
	1A 0F 08	Sector 26 at Side 1 Sector 15 at Side 1 Sector 8 at Side 1	C + 1	NC	R = 01	NC
1	1A 0F 08	Sector 1 to 25 at Side 0 Sector 1 to 14 at Side 0 Sector 1 to 7 at Side 0	NC	NC	R + 1	NC
	1A 0F 08	Sector 26 at Side 0 Sector 15 at Side 0 Sector 8 at Side 0	NC	LSB	R = 01	NC
	1A 0F 08	Sector 1 to 25 at Side 1 Sector 1 to 14 at Side 1 Sector 1 to 7 at Side 1	NC	NC	R + 1	NC
	1A 0F 08	Sector 26 at Side 1 Sector 15 at Side 1 Sector 8 at Side 1	C + 1	LSB	R = 01	NC

Notes: 1. NC (No Change): The same value as the one at the beginning of command execution

2. LSB (Least Significant Bit): The least significant bit of H is complemented.

WRITE DATA

A set of nine (9) bytes are required to set the FDC into the Write Data mode. After the Write Data command has been issued the FDC loads the head (if it is in the unloaded state), waits the specified head settling time (defined in the Specify Command), and begins reading ID Fields. When the current sector number ("R"), stored in the ID Register (IDR) compares with the sector

number read off the diskette, then the FDC takes data from the processor byte-by-byte via the data bus, and outputs it to the FDD.

After writing data into the current sector, the Sector Number stored in "R" is incremented by one, and the next data field is written into. The FDC continues this "Multi-Sector Write Operation" until the issuance of a Terminal Count signal. If a Terminal Count signal is sent to the FDC it continues writing into the current sector to complete the data field. If the Terminal Count signal is received while a data field is being written then the remainder of the data field is filled with 00 (zeros).

The FDC reads the ID field of each sector and checks the CRC bytes. If the FDC detects a read error (incorrect CRC) in one of the ID Fields, it sets the DE (Data Error) flag of Status Register 1 to a 1 (high), and terminates the Write Data Command. (Status Register 0 also has bits 7 and 6 set to 0 and 1 respectively.)

The Write Command operates in much the same manner as the Read Command. The following items are the same; refer to the Read Data Command for details:

- Transfer Capacity
- EN (End of Cylinder) Flag
- ND (No Data) Flag
- Head Unload Time Interval
- ID Information when the processor terminates command (see Table 2)
- Definition of DTL when N = 0 and when N ≠ 0

In the Write Data mode, data transfers between the processor and FDC must occur every 31 μs in the FM mode, and every 15 μs in the MFM mode. If the time interval between data transfers is longer than this then the FDC sets the OR (Over Run) flag in Status Register 1 to a 1 (high), and terminates the Write Data Command.

For mini-floppies, multiple track writes are usually not permitted. This is because of the turn-off time of the erase head coils—the head switches tracks before the erase head turns off. Therefore the system should typically wait 1.3 mS before attempting to step or change sides.

WRITE DELETED DATA

This command is the same as the Write Data Command except a Deleted Data Address Mark is written at the beginning of the Data Field instead of the normal Data Address Mark.

READ DELETED DATA

This command is the same as the Read Data Command except that when the FDC detects a Data Address Mark at the beginning of a Data Field (and SK = 0 (low)), it will read all the data in the sector and set the CM flag in Status Register 2 to a 1 (high), and then terminate the command. If SK = 1, then the FDC skips the sector with the Data Address Mark and reads the next sector.

READ A TRACK

This command is similar to READ DATA Command except that the entire data field is read continuously from each of the sectors of a track. Immediately after encountering the INDEX HOLE, the FDC starts reading all data fields on the track as continuous blocks of data. If the FDC finds an error in the ID or DATA CRC check bytes, it continues to read data from the track. The FDC compares the ID information read from each sector with the value stored in the IDR, and sets the ND flag of Status Register 1 to a 1 (high) if there is no comparison. Multi-track or skip operations are not allowed with this command.

This command terminates when EOT number of sectors have been read. If the FDC does not find an ID Address Mark on the diskette after it encounters the INDEX HOLE for the second time, then it sets the MA (missing address mark) flag in Status Register 1 to a 1 (high), and terminates the command. (Status Register 0 has bits 7 and 6 set to 0 and 1 respectively.)

READ ID

The READ ID Command is used to give the present position of the recording head. The FDC stores the values from the first ID Field it is able to read. If no proper ID Address Mark is found on the diskette, before the INDEX HOLE is encountered for the second time then the MA (Missing Address Mark) flag in Status Register 1 is set to a 1 (high), and if no data is found then the ND (No Data) flag is also set in Status Register 1 to a 1 (high) and the command is terminated.

FORMAT A TRACK

The Format Command allows an entire track to be formatted. After the INDEX HOLE is detected, Data is written on the Diskette: Gaps, Address Marks, ID Fields and Data Fields, all per the IBM System 34 (Double Density) or System 3740 (Single Density) Format are recorded. The particular format which will be written is controlled by the values programmed into N (number of bytes/sector), SC (sectors/cylinder), GPL (Gap Length), and D (Data Pattern) which are supplied by the processor during the Command Phase. The Data Field is filled with the Byte of data stored in D. The ID Field for each sector is supplied by the processor; that is, four data requests per sector are made by the FDC for C (Cylinder Number), H (Head Number), R (Sector Number) and N (Number of Bytes/Sector). This allows the diskette to be formatted with nonsequential sector numbers, if desired.

After formatting each sector, the processor must send new values for C, H, R, and N to the 8272A for each sector on the track. The contents of the R Register is incremented by one after each sector is formatted, thus, the R register contains a value of R + 1 when it is read during the Result Phase. This incrementing and formatting continues for the whole track until the FDC encounters the INDEX HOLE for the second time, whereupon it terminates the command.

If a FAULT signal is received from the FDD at the end of a write operation, then the FDC sets the EC flag of Status Register 0 to a 1 (high), and terminates the command after setting bits 7 and 6 of Status Register 0 to 0 and 1 respectively. Also the loss of a READY signal at the beginning of a command execution phase causes command termination.

Table 9 shows the relationship between N, SC, and GPL for various sector sizes:

Table 9. Sector Size Relationships.

8" STANDARD FLOPPY							5¼" MINI FLOPPY				
FORMAT	SECTOR SIZE	N	SC	GPL[1]	GPL[2]	REMARKS	SECTOR SIZE	N	SC	GPL[1]	GPL[2]
FM Mode	128 bytes/Sector	00	1A	07	1B	IBM Diskette 1	128 bytes/Sector	00	12	07	09
	256	01	0F	0E	2A	IBM Diskette 2	128	00	10	10	19
	512	02	08	1B	3A		256	01	[illegible]	18	30
	1024	03	04	47	[illegible]		512	02	04	46	87
	2048	04	02	C8	FF		1024	03	02	[illegible]	FF
	4096	05	01	C8	FF		2048	04	01	C8	FF
MFM Mode	256	01	1A	0E	36	IBM Diskette 2D	256	01	12	0A	0C
	512	02	0F	1B	54		256	01	10	20	32
	1024	03	08	35	74	IBM Diskette 2D	512	02	08	2A	50
	2048	04	04	99	FF		1024	03	04	80	F0
	4096	05	02	C8	FF		2048	04	02	[illegible]	FF
	8192	06	01	[illegible]	FF		4096	05	01	C8	FF

Note: 1. Suggested values of GPL in Read or Write Commands to avoid splice point between data field and ID field of contiguous sections.
2. Suggested values of GPL in format command.

SCAN COMMANDS

The SCAN Commands allow data which is being read from the diskette to be compared against data which is being supplied from the main system (Processor in NON-DMA mode, and DMA Controller in DMA mode). The FDC compares the data on a byte-by-byte basis, and looks for a sector of data which meets the conditions of $D_{FDD} = D_{Processor}$, $D_{FDD} < D_{Processor}$, or $D_{FDD} > D_{Processor}$. Ones complement arithmetic is used for comparison (FF = largest number, 00 = smallest number). After a whole sector of data is compared, if the conditions are not met, the sector number is incremented (R + STP → R), and the scan operation is continued. The scan operation continues until one of the following conditions occur; the conditions for scan are met (equal, low, or high), the last sector on the track is reached (EOT), or the terminal count signal is received.

If the conditions for scan are met then the FDC sets the SH (Scan Hit) flag of Status Register 2 to a 1 (high), and terminates the Scan Command. If the conditions for scan are not met between the starting sector (as specified by R) and the last sector on the cylinder (EOT), then the FDC sets the SN (Scan Not Satisfied) flag of Status Register 2 to a 1 (high), and terminates the Scan Command. The receipt of a TERMINAL COUNT signal from the Processor or DMA Controller during the scan operation will cause the FDC to complete the comparison of the particular byte which is in process, and then to terminate the command. Table 10 shows the status of bits SH and SN under various conditions of SCAN.

Table 10. Scan Status Codes

COMMAND	STATUS REGISTER 2		COMMENTS
	BIT 2 = SN	BIT 3 = SH	
Scan Equal	0	1	$D_{FDD} = D_{Processor}$
	1	0	$D_{FDD} \neq D_{Processor}$
Scan Low or Equal	0	1	$D_{FDD} = D_{Processor}$
	0	0	$D_{FDD} < D_{Processor}$
	1	0	$D_{FDD} \nless D_{Processor}$
Scan High or Equal	0	1	$D_{FDD} = D_{Processor}$
	0	0	$D_{FDD} > D_{Processor}$
	1	0	$D_{FDD} \ngtr D_{Processor}$

If the FDC encounters a Deleted Data Address Mark on one of the sectors (and SK = 0), then it regards the sector as the last sector on the cylinder, sets CM (Control Mark) flag of Status Register 2 to a 1 (high) and terminates the command. If SK = 1, the FDC skips the sector with the Deleted Address Mark, and reads the next sector. In the second case (SK = 1), the FDC sets the CM (Control Mark) flag of Status Register 2 to a 1 (high) in order to show that a Deleted Sector had been encountered.

When either the STP (contiguous sectors STP = 01, or alternate sectors STP = 02 sectors are read) or the MT (Multi-Track) are programmed, it is necessary to remember that the last sector on the track must be read. For example, if STP = 02, MT = 0, the sectors are numbered sequentially 1 through 26, and we start the Scan Command at sector 21; the following will happen. Sectors 21, 23, and 25 will be read, then the next sector (26) will be skipped and the Index Hole will be encountered before the EOT value of 26 can be read. This will result in an abnormal termination of the command. If the EOT had been set at 25 or the scanning started at sector 20, then the Scan Command would be completed in a normal manner.

During the Scan Command data is supplied by either the processor or DMA Controller for comparison against the data read from the diskette. In order to avoid having the OR (Over Run) flag set in Status Register 1, it is necessary to have the data available in less than 27 μs (FM Mode) or 13 μs (MFM Mode). If an Overrun occurs the FDC terminates the command.

SEEK

The read/write head within the FDD is moved from cylinder to cylinder under control of the Seek Command. The FDC compares the PCN (Present Cylinder Number) which is the current head position with the NCN (New Cylinder Number), and performs the following operation if there is a difference:

PCN < NCN: Direction signal to FDD set to a 1 (high), and Step Pulses are issued. (Step In.)

PCN > NCN: Direction signal to FDD set to a 0 (low), and Step Pulses are issued. (Step Out.)

The rate at which Step Pulses are issued is controlled by SRT (Stepping Rate Time) in the SPECIFY Command. After each Step Pulse is issued NCN is compared against PCN, and when NCN = PCN, then the SE (Seek End) flag is set in Status Register 0 to a 1 (high), and the command is terminated.

During the Command Phase of the Seek operation the FDC is in the FDC BUSY state, but during the Execution Phase it is in the NON BUSY state. While the FDC is in the NON BUSY state, another Seek Command may be issued, and in this manner parallel seek operations may be done on up to 4 Drives at once.

If an FDD is in a NOT READY state at the beginning of the command execution phase or during the seek operation, then the NR (NOT READY) flag is set in Status Register 0 to a 1 (high), and the command is terminated.

Note that the 8272A Read and Write Commands do not have implied Seeks. Any R/W command should be preceded by: 1) Seek Command; 2) Sense Interrupt Status; and 3) Read ID.

RECALIBRATE

This command causes the read/write head within the FDD to retract to the Track 0 position. The FDC clears the contents of the PCN counter, and checks the status of the Track 0 signal from the FDD. As long as the Track 0 signal is low, the Direction signal remains 1 (high) and Step Pulses are issued. When the Track 0 signal goes high, the SE (SEEK END) flag in Status Register 0 is set to a 1 (high) and the command is terminated. If the Track 0 signal is still low after 77 Step Pulses have been issued, the FDC sets the SE (SEEK END) and EC (EQUIPMENT CHECK) flags of Status Register 0 to both 1s (highs), and terminates the command.

The ability to overlap RECALIBRATE Commands to multiple FDDs, and the loss of the READY signal, as described in the SEEK Command, also applies to the RECALIBRATE Command.

SENSE INTERRUPT STATUS

An Interrupt signal is generated by the FDC for one of the following reasons:

1. Upon entering the Result Phase of:
   a. Read Data Command
   b. Read a Track Command
   c. Read ID Command
   d. Read Deleted Data Command
   e. Write Data Command
   f. Format a Cylinder Command
   g. Write Deleted Data Command
   h. Scan Commands
2. Ready Line of FDD changes state
3. End of Seek or Recalibrate Command
4. During Execution Phase in the NON-DMA Mode

Interrupts caused by reasons 1 and 4 above occur during normal command operations and are easily discernible by the processor. However, interrupts caused by reasons 2 and 3 above may be uniquely identified with the aid of the Sense Interrupt Status Command. This command when issued resets the interrupt signal and via bits 5, 6, and 7 of Status Register 0 identifies the cause of the interrupt.

Neither the Seek or Recalibrate Command have a Result Phase. Therefore, it is mandatory to use the Sense Interrupt Status Command after these commands to effectively terminate them and to provide verification of the head position (PCN).

Table 11. Seek, Interrupt Codes

SEEK END BIT 5	INTERRUPT CODE		CAUSE
	BIT 6	BIT 7	
0	1	1	Ready Line changed state, either polarity
1	0	0	Normal Termination of Seek or Recalibrate Command
1	1	0	Abnormal Termination of Seek or Recalibrate Command

SPECIFY

The Specify Command sets the initial values for each of the three internal timers. The HUT (Head Unload Time) defines the time from the end of the Execution Phase of one of the Read/Write Commands to the head unload state. This timer is programmable from 16 to 240 ms in increments of 16 ms (01 = 16 ms, 02 = 32 ms . . . . OF = 240 ms). The SRT (Step Rate Time) defines the time interval between adjacent step pulses. This timer is programmable from 1 to 16 ms in increments of 1 ms (F = 1 ms, E = 2 ms, D = 3 ms, etc.). The HLT (Head Load Time) defines the time between when the Head Load signal goes high and when the Read/Write operation starts. This timer is programmable from 2 to 254 ms in increments of 2 ms (01 = 2 ms, 02 = 4 ms, 03 = 6 ms . . . . FE = 254 ms).

The step rate should be programmed 1 mS longer than the minimum time required by the drive.

The time intervals mentioned above are a direct function of the clock (CLK on pin 19). Times indicated above are for an 8 MHz clock, if the clock was reduced to 4 MHz (mini-floppy application) then all time intervals are increased by a factor of 2.

The choice of DMA or NON-DMA operation is made by the ND (NON-DMA) bit. When this bit is high (ND = 1) the NON-DMA mode is selected, and when ND = 0 the DMA mode is selected.

SENSE DRIVE STATUS

This command may be used by the processor whenever it wishes to obtain the status of the FDDs. Status Register 3 contains the Drive Status Information.

INVALID

If an invalid command is sent to the FDC (a command not defined above), then the FDC will terminate the command. No interrupt is generated by the 8272A during this condition. Bit 6 and bit 7 (DIO and RQM) in the Main Status Register are both high ("1") indicating to the processor that the 8272A is in the Result Phase and the contents of Status Register 0 (ST0) must be read. When the processor reads Status Register 0 it will find an 80H indicating an invalid command was received.

A Sense Interrupt Status Command must be sent after a Seek or Recalibrate interrupt, otherwise the FDC will consider the next command to be an Invalid Command.

In some applications the user may wish to use this command as a No-Op command, to place the FDC in a standby or no operation state.

Table 12. Status Registers

BIT NO.	BIT NAME	BIT SYMBOL	DESCRIPTION
			STATUS REGISTER 0
D_7	Interrupt Code	IC	$D_7 = 0$ and $D_6 = 0$ Normal Termination of Command, (NT). Command was completed and properly executed.
D_6			$D_7 = 0$ and $D_6 = 1$ Abnormal Termination of Command, (AT). Execution of Command was started, but was not successfully completed.
			$D_7 = 1$ and $D_6 = 0$ Invalid Command issue, (IC). Command which was issued was never started.
			$D_7 = 1$ and $D_6 = 1$ Abnormal Termination because during command execution the ready signal from FDD changed state.
D_5	Seek End	SE	When the FDC completes the SEEK Command, this flag is set to 1 (high).
D_4	Equipment Check	EC	If a fault Signal is received from the FDD, or if the Track 0 Signal fails to occur after 77 Step Pulses (Recalibrate Command) then this flag is set.
D_3	Not Ready	NR	When the FDD is in the not-ready state and a read or write command is issued, this flag is set. If a read or write command is issued to Side 1 of a single sided drive, then this flag is set
D_2	Head Address	HD	This flag is used to indicate the state of the head at Interrupt.
D_1	Unit Select 1	US 1	These flags are used to indicate a Drive Unit Number at Interrupt
D_0	Unit Select 0	US 0	
			STATUS REGISTER 1
D_7	End of Cylinder	EN	When the FDC tries to access a Sector beyond the final Sector of a Cylinder, this flag is set.
D_6			Not used. This bit is always 0 (low).
D_5	Data Error	DE	When the FDC detects a CRC error in either the ID field or the data field, this flag is set.
D_4	Over Run	OR	If the FDC is not serviced by the main-systems during data transfers, within a certain time interval, this flag is set.
D_3			Not used. This bit always 0 (low).
D_2	No Data	ND	During execution of READ DATA, WRITE DELETED DATA or SCAN Command, if the FDC cannot find the Sector specified in the IDR Register, this flag is set.
			During executing the READ ID Command, if the FDC cannot read the ID field without an error, then this flag is set.
			During the execution of the READ A Cylinder Command, if the starting sector cannot be found, then this flag is set
			STATUS REGISTER 1 (CONT.)
D_1	Not Writable	NW	During execution of WRITE DATA, WRITE DELETED DATA or Format A Cylinder Command, if the FDC detects a write protect signal from the FDD, then this flag is set.
D_0	Missing Address Mark	MA	If the FDC cannot detect the ID Address Mark after encountering the index hole twice, then this flag is set.
			If the FDC cannot detect the Data Address Mark or Deleted Data Address Mark, this flag is set. Also at the same time, the MD (Missing Address Mark in Data Field) of Status Register 2 is set.
			STATUS REGISTER 2
D_7			Not used. This bit is always 0 (low).
D_6	Control Mark	CM	During executing the READ DATA or SCAN Command, if the FDC encounters a Sector which contains a Deleted Data Address Mark, this flag is set.
D_5	Data Error in Data Field	DD	If the FDC detects a CRC error in the data field then this flag is set.
D_4	Wrong Cylinder	WC	This bit is related with the ND bit, and when the contents of C on the medium is different from that stored in the IDR, this flag is set
D_3	Scan Equal Hit	SH	During execution, the SCAN Command, if the condition of "equal" is satisfied, this flag is set
D_2	Scan Not Satisfied	SN	During executing the SCAN Command, if the FDC cannot find a Sector on the cylinder which meets the condition, then this flag is set.
D_1	Bad Cylinder	BC	This bit is related with the ND bit, and when the content of C on the medium is different from that stored in the IDR and the content of C is FF, then this flag is set.
D_0	Missing Address Mark in Data Field	MD	When data is read from the medium, if the FDC cannot find a Data Address Mark or Deleted Data Address Mark, then this flag is set
			STATUS REGISTER 3
D_7	Fault	FT	This bit is used to indicate the status of the Fault signal from the FDD.
D_6	Write Protected	WP	This bit is used to indicate the status of the Write Protected signal from the FDD.
D_5	Ready	RDY	This bit is used to indicate the status of the Ready signal from the FDD.
D_4	Track 0	T0	This bit is used to indicate the status of the Track 0 signal from the FDD
D_3	Two Side	TS	This bit is used to indicate the status of the Two Side signal from the FDD.
D_2	Head Address	HD	This bit is used to indicate the status of Side Select signal to the FDD.
D_1	Unit Select 1	US 1	This bit is used to indicate the status of the Unit Select 1 signal to the FDD.
D_0	Unit Select 0	US 0	This bit is used to indicate the status of the Unit Select 0 signal to the FDD.

ABSOLUTE MAXIMUM RATINGS*

Operating Temperature ..... 0°C to +70°C
Storage Temperature ..... −40°C to +125°C
All Output Voltages ..... −0.5 to +7 Volts
All Input Voltages ..... −0.5 to +7 Volts
Supply Voltage V_{CC} ..... −0.5 to +7 Volts
Power Dissipation ..... 1 Watt

*T_A = 25°C

NOTICE: Stress above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. CHARACTERISTICS (T_A = 0°C to +70°C, V_{CC} = +5V ±10%)

Symbol	Parameter	Limits Min.	Limits Max.	Unit	Test Conditions
V_{IL}	Input Low Voltage	−0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC}+0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2.0 mA
V_{OH}	Output High Voltage	2.4	V_{CC}	V	I_{OH} = −400 μA
I_{CC}	V_{CC} Supply Current		120	mA	
I_{IL}	Input Load Current (All Input Pins)		10 −10	μA μA	V_{IN} = V_{CC} V_{IN} = 0V
I_{LOH}	High Level Output Leakage Current		10	μA	V_{OUT} = V_{CC}
I_{OFL}	Output Float Leakage Current		±10	μA	0.45V ≤ V_{OUT} ≤ V_{CC}

CAPACITANCE (T_A = 25°C, f_c = 1 MHz, V_{CC} = 0V)

Symbol	Parameter	Limits Min.	Limits Max.	Unit	Test Conditions
$C_{IN(\Phi)}$	Clock Input Capacitance		20	pF	All Pins Except Pin Under Test Tied to AC Ground
C_{IN}	Input Capacitance		10	pF	
$C_{I/O}$	Input/Output Capacitance		20	pF	

A.C. CHARACTERISTICS (T_A0°C to +70°C, V_{CC} = +5.0V ±10%)

CLOCK TIMING

Symbol	Parameter	Min.	Max.	Unit	Notes
t_{CY}	Clock Period	120	500	ns	Note 5
t_{CH}	Clock High Period	40		ns	Note 4, 5
t_{RST}	Reset Width	14		t_{CY}	

READ CYCLE

t_{AR}	Select Setup to $\overline{RD}$↓	0		ns	
t_{RA}	Select Hold from $\overline{RD}$↑	0		ns	
t_{RR}	$\overline{RD}$ Pulse Width	250		ns	
t_{RD}	Data Delay from $\overline{RD}$↓		200	ns	
t_{DF}	Output Float Delay	20	100	ns	

A.C. CHARACTERISTICS (Continued) (T_A 0°C to +70°C, V_{CC} = +5.0V ± 10%)

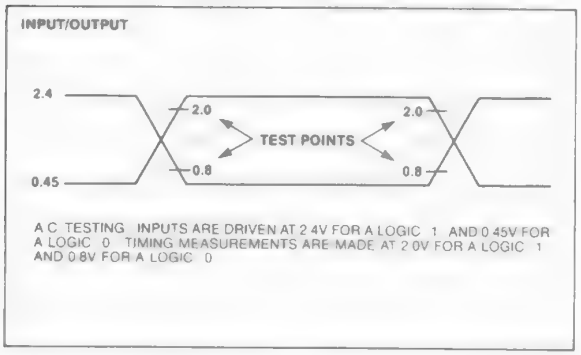
WRITE CYCLE

Symbol	Parameter	Typ.[1]	Min.	Max.	Unit	Notes
tAW	Select Setup to $\overline{WR}$↓		0		ns	
tWA	Select Hold from $\overline{WR}$↑		0		ns	
tWW	$\overline{WR}$ Pulse Width		250		ns	
tDW	Data Setup to $\overline{WR}$↑		150		ns	
tWD	Data Hold from $\overline{WR}$↑		5		ns	
INTERRUPTS						
tRI	INT Delay from $\overline{RD}$↑			500	ns	Note 6
tWI	INT Delay from $\overline{WR}$↑			500	ns	Note 6
DMA						
tRQCY	DRQ Cycle Period		13		µs	Note 6
tAKRQ	$\overline{DACK}$↓ to DRQ↓			200	ns	
tRQR	DRQ↑ to $\overline{RD}$↓		800		ns	Note 6
tRQW	DRQ↑ to $\overline{WR}$↓		250		ns	Note 6
tRQRW	DRQ↑ to $\overline{RD}$↑ or $\overline{WR}$↑			12	µs	Note 6
FDD INTERFACE						
tWCY	WCK Cycle Time	2 or 4 1 or 2			µs	MFM = 0 MFM = 1 Note 2
tWCH	WCK High Time	250	80	350	ns	
tCP	Pre-Shift Delay from WCK↑		20	100	ns	
tCD	WDA Delay from WCK↑		20	100	ns	
tWDD	Write Data Width		tWCH − 50		ns	
tWE	WE↑ to WCK↑ or WE↓ to WCK↓ Delay		20	100	ns	
tWWCY	Window Cycle Time	2 1			µs	MFM = 0 MFM = 1
tWRD	Window Setup to RDD↑		15		ns	
tRDW	Window Hold from RDD↓		15		ns	
tRDD	RDD Active Time (HIGH)		40		ns	
FDD SEEK/DIRECTION/STEP						
tUS	$US_{0,1}$ Setup to $\overline{RW/SEEK}$↑		12		µs	Note 6
tSU	$US_{0,1}$ Hold after $\overline{RW/SEEK}$↓		15		µs	Note 6
tSD	$\overline{RW/SEEK}$ Setup to LCT/DIR		7		µs	Note 6
tDS	$\overline{RW/SEEK}$ Hold from LCT/DIR		30		µs	Note 6
tDST	LCT/DIR Setup to FR/STEP↑		1		µs	Note 6
tSTD	LCT/DIR Hold from FR/STEP↓		24		µs	Note 6
tSTU	DS_2 - Hold from FR/Step↓		5		µs	Note 6
tSTP	STEP Active Time (High)	5			µs	Note 6
tSC	STEP Cycle Time		33		µs	Note 3, 6
tFR	FAULT RESET Active Time (High)		8	10	µs	Note 6
tIDX	INDEX Pulse Width	10			tCY	
tTC	Terminal Count Width		1		tCY	

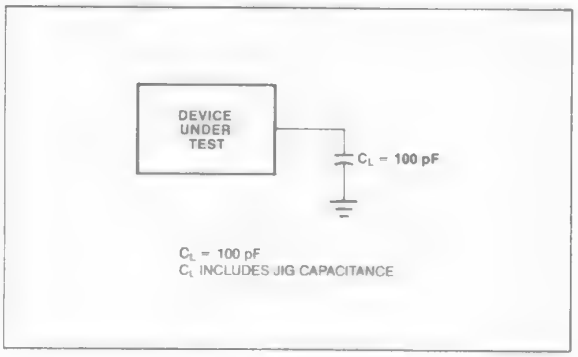
NOTES:

1. Typical values for T_A = 25°C and nominal supply voltage.
2. The former values are used for standard floppy and the latter values are used for mini-floppies.
3. tSC = 33 µs min. is for different drive units. In the case of same unit, tSC can be ranged from 1 ms to 16 ms with 8 MHz clock period, and 2 ms to 32 ms with 4 MHz clock, under software control.
4. From 2.0V to +2.0V.
5. At 4 MHz, the clock duty cycle may range from 16% to 76%. Using an 8 MHz clock the duty cycle can range from 32% to 52%. Duty cycle is defined as: D.C. = 100 (tCH ÷ tCY) with typical rise and fall times of 5 ns.
6. The specified values listed are for an 8 MHz clock period. Multiply timings by 2 when using a 4 MHz clock period.

A.C. TESTING INPUT, OUTPUT WAVEFORM

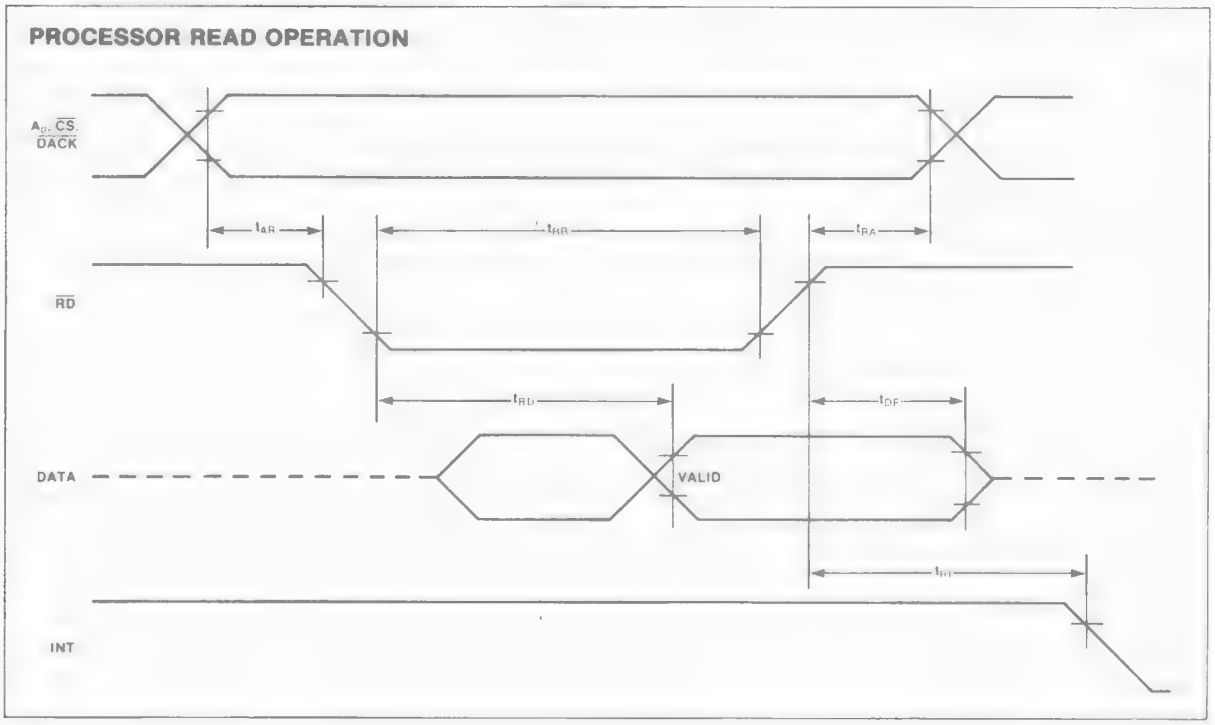


A.C. TESTING LOAD CIRCUIT



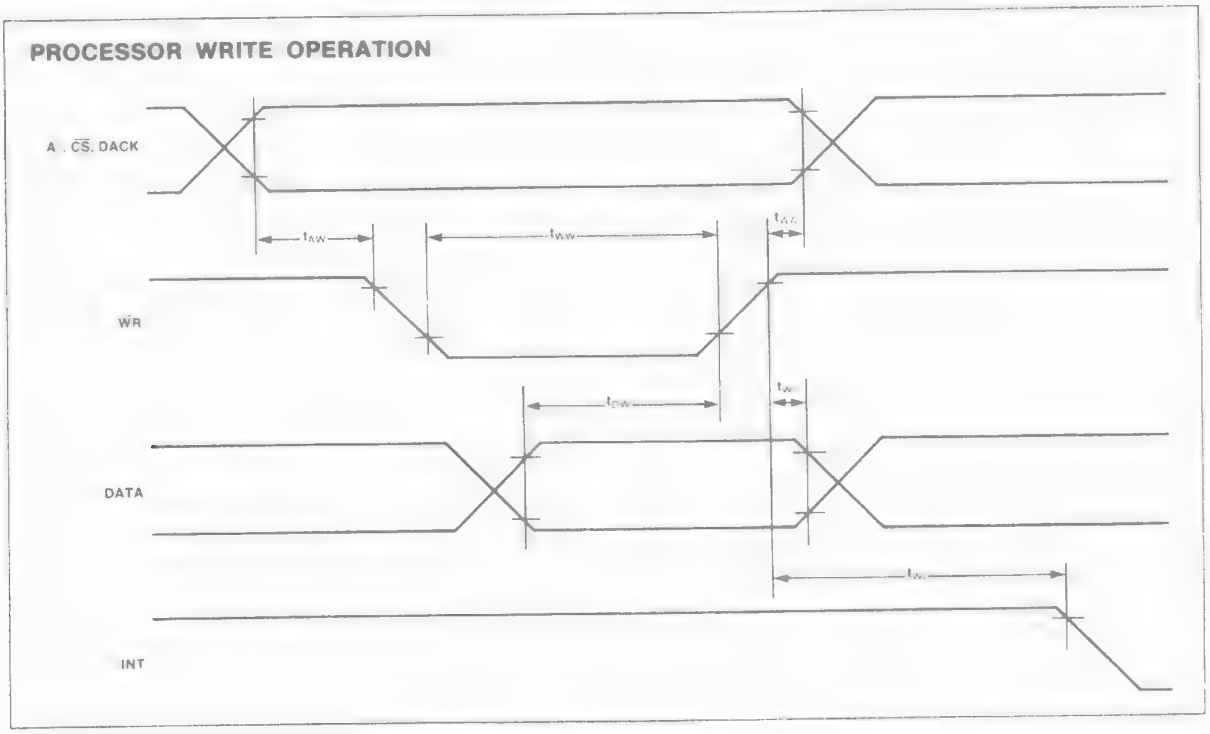
WAVEFORMS

PROCESSOR READ OPERATION

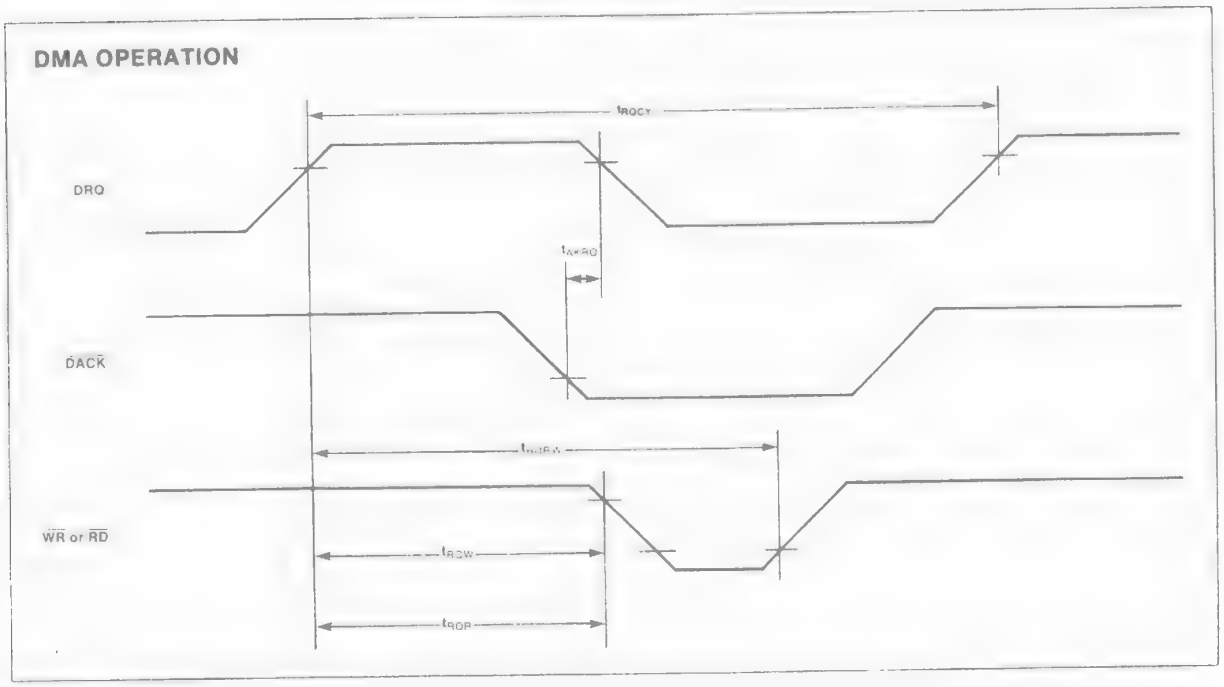


WAVEFORMS (Continued)

PROCESSOR WRITE OPERATION



DMA OPERATION



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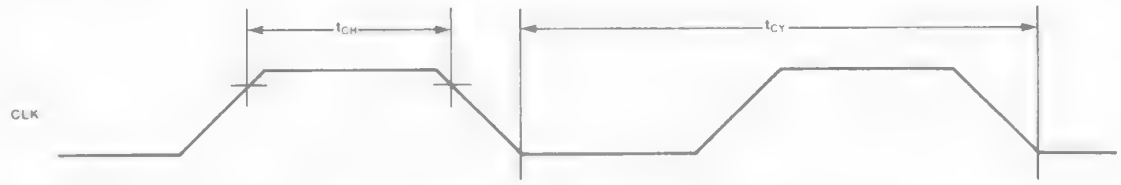
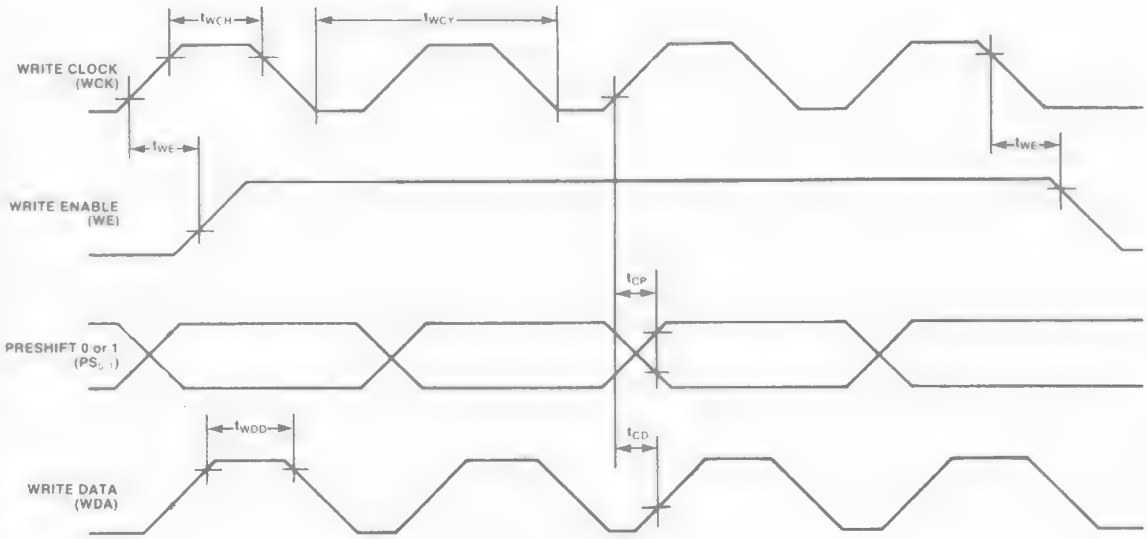
WAVEFORMS (Continued)

CLOCK TIMING



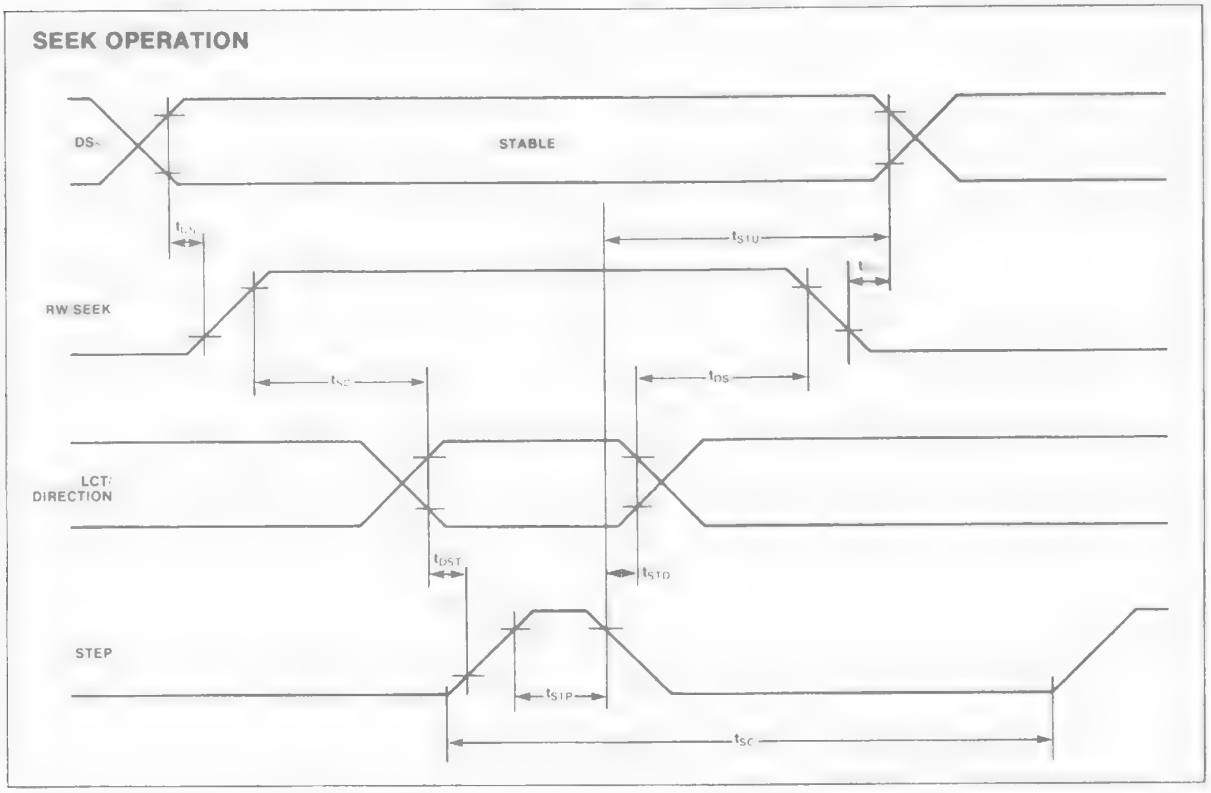
FDD WRITE OPERATION



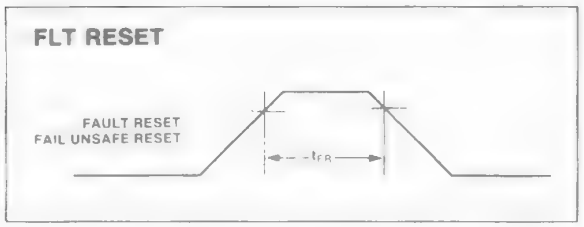
	PRESHIFT 0	PRESHIFT 1
NORMAL	0	0
LATE	0	1
EARLY	1	0
INVALID	1	1

WAVEFORMS (Continued)

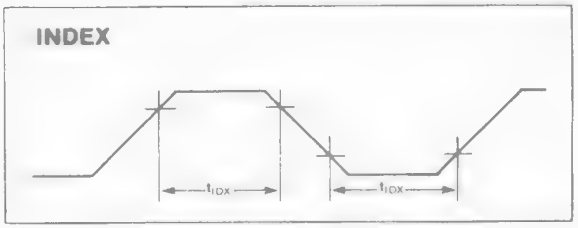
SEEK OPERATION



FLT RESET



INDEX



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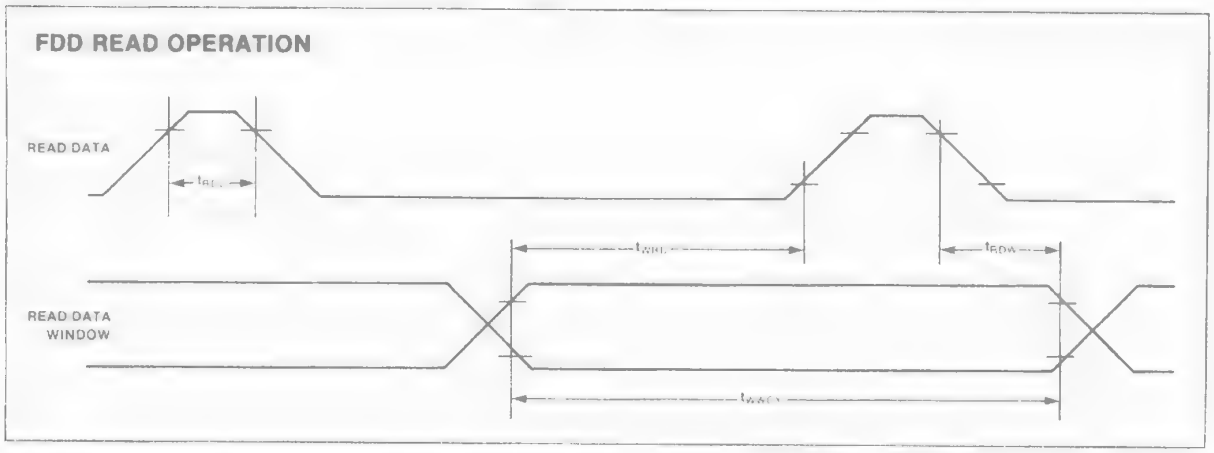
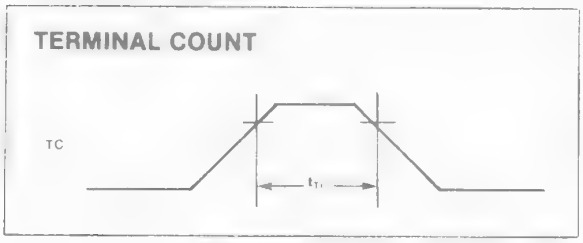
WAVEFORMS (Continued)

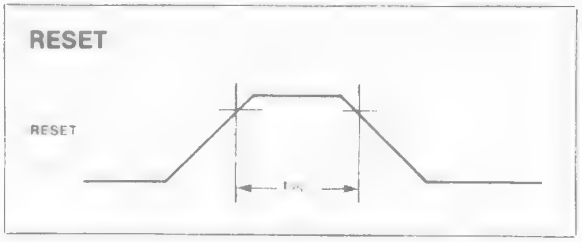
FDD READ OPERATION



TERMINAL COUNT



RESET



8273, 8273-4, 8273-8
PROGRAMMABLE HDLC/SDLC PROTOCOL CONTROLLER

- **CCITT X.25 Compatible**
- **HDLC/SDLC Compatible**
- **Full Duplex, Half Duplex, or Loop SDLC Operation**
- **Up to 64K Baud Synchronous Transfers**
- **Automatic FCS (CRC) Generation and Checking**
- **Up to 9.6K Baud with On-Board Phase Locked Loop**
- **Programmable NRZI Encode/Decode**
- **Two User Programmable Modem Control Ports**
- **Digital Phase Locked Loop Clock Recovery**
- **Minimum CPU Overhead**
- **Fully Compatible with 8048/8080/8085/8088/8086 CPUs**
- **Single +5V Supply**

The Intel® 8273 Programmable HDLC/SDLC Protocol Controller is a dedicated device designed to support the ISO/CCITT's HDLC and IBM's SDLC communication line protocols. It is fully compatible with Intel's new high performance microcomputer systems such as the MCS-88/86™. A frame level command set is achieved by a unique microprogrammed dual processor chip architecture. The processing capability supported by the 8273 relieves the system CPU of the low level real-time tasks normally associated with controllers.

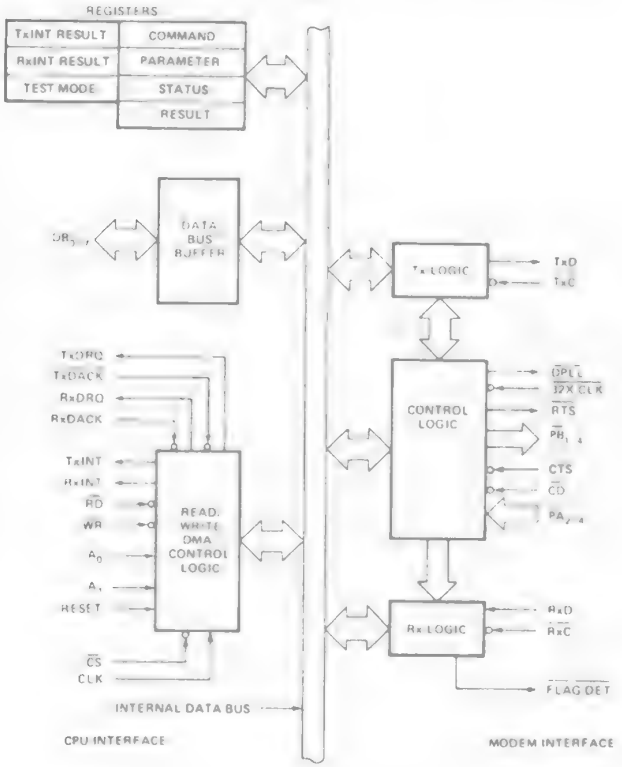


Figure 1. Block Diagram

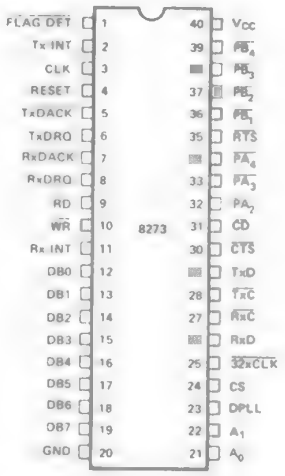


Figure 2. Pin Configuration

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MAY 1982
ORDER NUMBER: 210279-001

A BRIEF DESCRIPTION OF HDLC/SDLC PROTOCOLS

General

The High Level Data Link Control (HDLC) is a standard communication link protocol established by International Standards Organization (ISO). HDLC is the discipline used to implement ISO X.25 packet switching systems.

The Synchronous Data Link Control (SDLC) is an IBM communication link protocol used to implement the System Network Architecture (SNA). Both the protocols are bit oriented, code independent, and ideal for full duplex communication. Some common applications include terminal to terminal, terminal to CPU, CPU to CPU, satellite communication, packet switching and other high speed data links. In systems which require expensive cabling and interconnect hardware, any of the two protocols could be used to simplify interfacing (by going serial), thereby reducing interconnect hardware costs. Since both the protocols are speed independent, reducing interconnect hardware could become an important application.

Network

In both the HDLC and SDLC line protocols, according to a pre-assigned hierarchy, a PRIMARY (Control) STATION controls the overall network (data link) and issues commands to the SECONDARY (Slave) STATIONS. The latter comply with instructions and respond by sending appropriate RESPONSES. Whenever a transmitting station must end transmission prematurely it sends an ABORT character. Upon detecting an abort character, a receiving station ignores the transmission block called a FRAME. Time fill between frames can be accomplished by transmitting either continuous frame preambles called FLAGS or an abort character. A time fill within a frame is not permitted. Whenever a station receives a string of more that fifteen consecutive ones, the station goes into an IDLE state.

Frames

A single communication element is called a FRAME which can be used for both Link Control and data transfer purposes. The elements of a frame are the beginning eight bit FLAG (F) consisting of one zero, six ones, and a zero, an eight bit ADDRESS FIELD (A), an eight bit CONTROL FIELD (C), a variable (N-bit) INFORMATION FIELD (I), a sixteen bit FRAME CHECK SEQUENCE (FCS), and an eight bit end FLAG (F), having the same bit pattern as the beginning flag. In HDLC the Address (A) and Control (C) bytes are extendable. The HDLC and the SDLC use three types of frames; an Information Frame is used to transfer data, a Supervisory Frame is used for control purposes, and a Non-sequenced Frame is used for initialization and control of the secondary stations.

Frame Characteristics

An important characteristic of a frame is that its contents are made code transparent by use of a zero bit insertion and deletion technique. Thus, the user can adopt any format or code suitable for his system — it may even be a computer word length or a "memory dump". The frame is bit oriented that is, bits, not characters in each field, have specific meanings. The Frame Check Sequence (FCS) is an error detection scheme similar to the Cyclic Redundancy Checkword (CRC) widely used in magnetic disk storage devices. The Command and Response information frames contain sequence numbers in the control fields identifying the sent and received frames. The sequence numbers are used in Error Recovery Procedures (ERP) and as implicit acknowledgement of frame communication, enhancing the true full-duplex nature of the HDLC/SDLC protocols.

In contrast, BISYNC is basically half-duplex (two way alternate) because of necessity to transmit immediate acknowledgement frames. HDLC/SDLC therefore saves propagation delay times and have a potential of twice the throughput rate of BISYNC.

It is possible to use HDLC or SDLC over half duplex lines but there is a corresponding loss in throughput because both are primarily designed for full-duplex communication. As in any synchronous system, the bit rate is determined by the clock bits supplied by the modem, protocols themselves are speed independent.

A byproduct of the use of zero-bit insertion-deletion technique is the non-return-to-zero invert (NRZI) data transmission/reception compatibility. The latter allows HDLC/SDLC protocols to be used with asynchronous data communication hardware in which the clocks are derived from the NRZI encoded data.

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Standard Network Access Protocol Specification, DATAPAC, Trans-Canada Telephone System CCG111
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System Network Architecture Format and Protocol, IBM GA 27-3112

OPENING FLAG (F)	ADDRESS FIELD (A)	CONTROL FIELD (C)	INFORMATION FIELD (I)	FRAME CHECK SEQUENCE (FCS)	CLOSING FLAG (F)
01111110	8 BITS	8 BITS	VARIABLE LENGTH (ONLY IN I FRAMES)	16 BITS	01111110

Figure 3. Frame Format

AFN-00743C

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
V_{CC}	40		**Power Supply:** +5V Supply.
GND	20		**Ground:** Ground.
RESET	4	I	**Reset:** A high signal on this pin will force the 8273 to an idle state. The 8273 will remain idle until a command is issued by the CPU. The modem interface output signals are forced high. Reset must be true for a minimum of 10 TCY.
$\overline{CS}$	24	I	**Chip Select:** The RD and WR inputs are enabled by the chip select input.
DB_7-DB_0	19-12	I/O	**Data Bus:** The Data Bus lines are bi-directional three-state lines which interface with the system Data Bus.
$\overline{WR}$	10	I	**Write Input:** The Write signal is used to control the transfer of either a command or data from CPU to the 8273.
$\overline{RD}$	[illegible]	I	**Read Input:** The Read signal is used to control the transfer of either a data byte or a status word from the 8273 to the CPU.
TxINT	2	O	**Transmitter Interrupt:** The Transmitter interrupt signal indicates that the transmitter logic requires service.
RxINT	11	O	**Receiver Interrupt:** The Receiver interrupt signal indicates that the Receiver logic requires service.
TxDRQ	[illegible]	O	**Transmitter Data Request:** Requests a transfer of data between memory and the 8273 for a transmit operation.
RxRDQ	8	O	**Receiver DMA Request:** Requests a transfer of data between the 8273 and memory for a receive operation.
$\overline{TxDACK}$	[illegible]	I	**Transmitter DMA Acknowledge:** The Transmitter DMA acknowledge signal notifies the 8273 that the TxDMA cycle has been granted.
$\overline{RxDACK}$	7	I	**Receiver DMA Acknowledge:** The Receiver DMA acknowledge signal notifies the 8273 that the RxDMA cycle has been granted.
A_1-A_0	22-21	I	**Address:** These two lines are CPU Interface Register Select lines.
TxD	29	O	**Transmitter Data:** This line transmits the serial data to the communication channel.
$\overline{TxC}$	[illegible]	I	**Transmitter Clock:** The transmitter clock is used to synchronize the transmit data.
RxD	26	I	**Receiver Data:** This line receives serial data from the communication channel.
$\overline{RxC}$	27	I	**Receiver Clock:** The Receiver Clock is used to synchronize the receive data.
$\overline{32X\ CLK}$	25	I	**32X Clock:** The 32X clock is used to provide clock recovery when an asynchronous modem is used. In loop configuration the loop station can run without an accurate 1X clock by using the 32X CLK in conjunction with the DPLL output. (This pin must be grounded when not used.)
$\overline{DPLL}$	23	O	**Digital Phase Locked Loop:** Digital Phase Locked Loop output can be tied to RxC and/or TxC when 1X clock is not available. DPLL is used with 32X CLK.
$\overline{FLAG\ DET}$	1	O	**Flag Detect:** Flag Detect signals that a flag (01111110) has been received by an active receiver.
$\overline{RTS}$	35	O	**Request to Send:** Request to Send signals that the 8273 is ready to transmit data.
$\overline{CTS}$	30	I	**Clear to Send:** Clear to Send signals that the modem is ready to accept data from the 8273.
$\overline{CD}$	31	I	**Carrier Detect:** Carrier Detect signals that the line transmission has started and the 8273 may begin to sample data on RxD line.
$\overline{PA}_{2-4}$	32-34	I	**General purpose Input ports:** The logic levels on these lines can be Read by the CPU through the Data Bus Buffer.
$\overline{PB}_{1-4}$	36-39	O	**General purpose output ports:** The CPU can write these output lines through Data Bus Buffer.
CLK	3	I	**Clock:** A square wave TTL clock.

FUNCTIONAL DESCRIPTION

General

The Intel® 8273 HDLC/SDLC controller is a microcomputer peripheral device which supports the International Standards Organization (ISO) High Level Data Link Control (HDLC), and IBM Synchronous Data Link Control (SDLC) communications protocols. This controller minimizes CPU software by supporting a comprehensive frame-level instruction set and by hardware implementation of the low level tasks associated with frame assembly/disassembly and data integrity. The 8273 can be used in either synchronous or asynchronous applications.

In asynchronous applications the data can be programmed to be encoded/decoded in NRZI code. The clock is derived from the NRZI data using a digital phase locked loop. The data transparency is achieved by using a zero-bit insertion/deletion technique. The frames are automatically checked for errors during reception by verifying the Frame Check Sequence (FCS); the FCS is automatically generated and appended before the final flag in transmit.

The 8273 recognizes and can generate flags (01111110) Abort, Idle, and GA (EOP) characters.

The 8273 can assume either a primary (control) or a secondary (slave) role. It can therefore be readily implemented in an SDLC loop configuration as typified by the IBM 3650 Retail Store System by programming the 8273 into a one-bit delay mode. In such a configuration, a two wire pair can be effectively used for data transfer between controllers and loop stations. The digital phase locked loop output pin can be used by the loop station without the presence of an accurate Tx clock.

CPU Interface

The CPU interface is optimized for the MCS-80/85™ bus with an 8257 DMA controller. However, the interface is flexible, and allows either DMA or non-DMA data transfers, interrupt or non-interrupt driven. It further allows maximum line utilization by providing early interrupt mechanism for buffered (only the information field can be transferred to memory) Tx command overlapping. It also provides separate Rx and Tx interrupt output channels for efficient operation. The 8273 keeps the interrupt request active until all the associated interrupt results have been read.

The CPU utilizes the CPU interface to specify commands and transfer data. It consists of seven registers addressed via $\overline{CS}$, A_1, A_0, $\overline{RD}$ and $\overline{WR}$ signals and two independent data registers for receive data and transmit data. A_1, A_0 are generally derived from two low order bits of the address bus. If an 8080 based CPU is utilized, the $\overline{RD}$ and $\overline{WR}$ signals may be driven by the 8228 $\overline{I/OR}$ and $\overline{I/OW}$. The table shows the seven register select decoding:

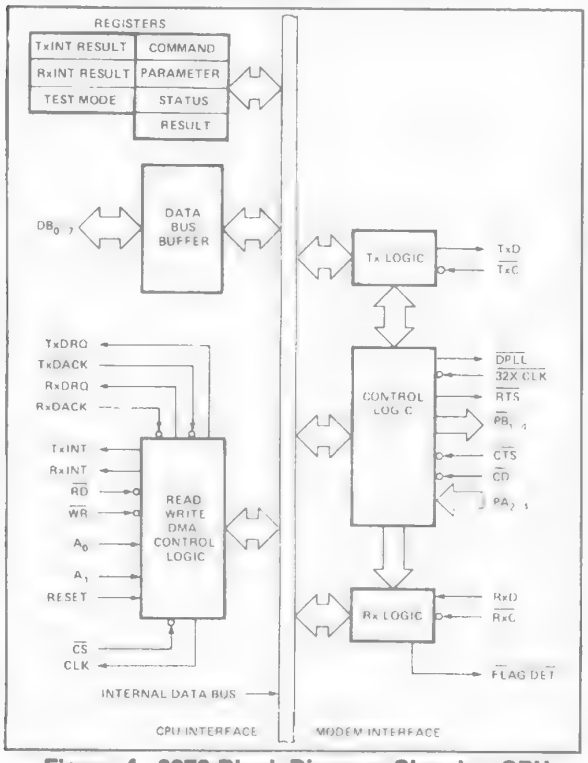


Figure 4. 8273 Block Diagram Showing CPU Interface Functions

A_1	A_0	$\overline{TxDACK}$	$\overline{RxDACK}$	$\overline{CS}$	$\overline{RD}$	$\overline{WR}$	Register
0	0	1	1	0	1	0	Command
0	0	1	1	0	0	1	Status
0	1	1	1	0	1	0	Parameter
0	1	1	1	0	0	1	Result
1	0	1	1	0	1	0	Reset
1	0	1	1	0	0	1	TxINT Result
1	1	1	1	0	1	0	—
1	1	1	1	0	0	1	RxINT Result
X	X	0	1	1	1	0	Transmit Data
X	X	1	0	1	0	1	Receive Data

Register Description

Command

Operations are initiated by writing an appropriate command in the Command Register.

Parameter

Parameters of commands that require additional information are written to this register.

Result

Contains an immediate result describing an outcome of an executed command.

Transmit Interrupt Result

Contains the outcome of 8273 transmit operation (good/bad completion).

Receive Interrupt Result

Contains the outcome of 8273 receive operation (good/bad completion), followed by additional results which detail the reason for interrupt.

Status

The status register reflects the state of the 8273 CPU Interface.

DMA Data Transfers

The 8273 CPU interface supports two independent data interfaces: receive data and transmit data. At high data transmission speeds the data transfer rate of the 8273 is great enough to justify the use of direct memory access (DMA) for the data transfers. When the 8273 is configured in DMA mode, the elements of the DMA interfaces are:

TxDRQ: Transmit DMA Request

Requests a transfer of data between memory and the 8273 for a transmit operation.

$\overline{TxDACK}$: Transmit DMA Acknowledge

The $\overline{TxDACK}$ signal notifies the 8273 that a transmit DMA cycle has been granted. It is also used with $\overline{WR}$ to transfer data to the 8273 in non-DMA mode. Note: $\overline{RD}$ must not be asserted while TxDACK is active.

RxDRQ: Receive DMA Request

Requests a transfer of data between the 8273 and memory for a receive operation.

$\overline{RxDACK}$: Receive DMA Acknowledge

The $\overline{RxDACK}$ signal notifies the 8273 that a receive DMA cycle has been granted. It is also used with $\overline{RD}$ to read data from the 8273 in non-DMA mode. Note: $\overline{WR}$ must not be asserted while $\overline{RxDACK}$ is active.

$\overline{RD}$, $\overline{WR}$: Read, Write

The $\overline{RD}$ and $\overline{WR}$ signals are used to specify the direction of the data transfer.

DMA transfers require the use of a DMA controller such as the Intel 8257. The function of the DMA controller is to provide sequential addresses and timing for the transfer, at a starting address determined by the CPU. Counting of data block lengths is performed by the 8273.

To request a DMA transfer the 8273 raises the appropriate DMA REQUEST. DMA ACKNOWLEDGE and READ enables DMA data onto the bus (independently of CHIP SELECT). DMA ACKNOWLEDGE and WRITE transfers DMA data to the 8273 (independent of CHIP SELECT).

It is also possible to configure the 8273 in the non-DMA data transfer mode. In this mode the CPU module must pass data to the 8273 in response to non-DMA data requests indicated by the status word.

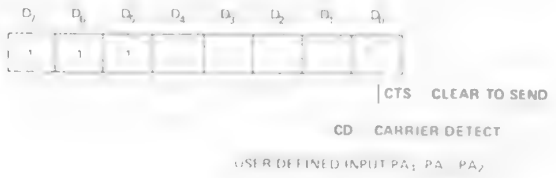
Modem Interface

The 8273 Modem interface provides both dedicated and user defined modem control functions. All the control signals are active low so that EIA RS-232C inverting drivers (MC 1488) and inverting receivers (MC 1489) may be used to interface to standard modems. For asynchronous operation, this interface supports programmable NRZI data encode/decode, a digital phase locked loop for efficient clock extraction from NRZI data, and modem control ports with automatic $\overline{CTS}$, $\overline{CD}$ monitoring and $\overline{RTS}$ generation. This interface also allows the 8273 to operate in PRE-FRAME SYNC mode in which the 8273 prefixes 16 transitions to a frame to synchronize idle lines before transmission of the first flag.

It should be noted that all the 8273 port operations deal with logical values, for instance, bit D0 of Port A will be a one when $\overline{CTS}$ (Pin 30) is a physical zero (logical one).

Port A — Input Port

During operation, the 8273 interrogates input pins $\overline{CTS}$ (Clear to Send) and $\overline{CD}$ (Carrier Detect). $\overline{CTS}$ is used to condition the start of a transmission. If during transmission $\overline{CTS}$ is lost the 8273 generates an interrupt. During reception, if $\overline{CD}$ is lost, the 8273 generates an interrupt.



The user defined input bits correspond to the 8273 PA_4, PA_3 and PA_2 pins. The 8273 does not interrogate or manipulate these bits.

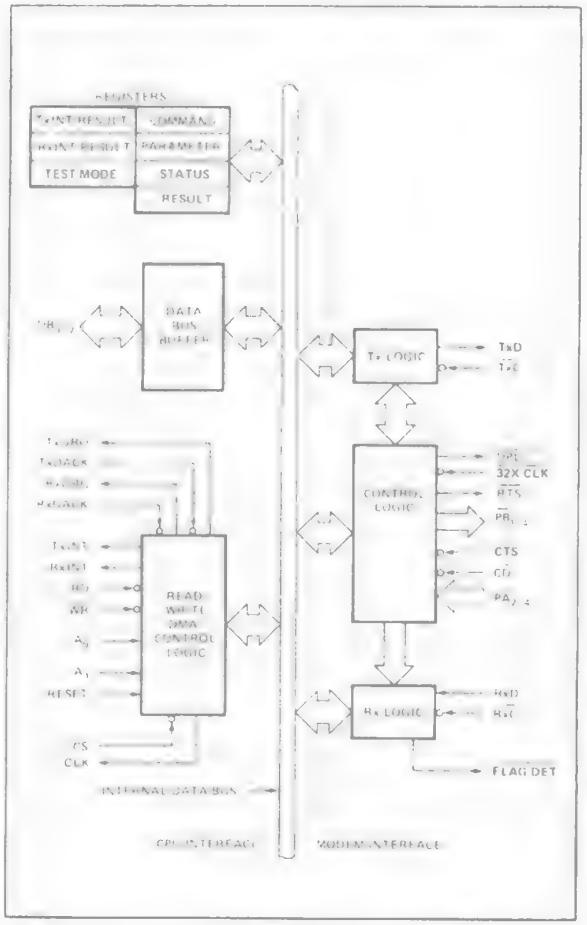


Figure 5. 8273 Block Diagram Showing Control Logic Functions

Port B - Output Port

During normal operation, if the CPU sets $\overline{RTS}$ active, the 8273 will not change this pin; however, if the CPU sets $\overline{RTS}$ inactive, the 8273 will activate it before each transmission and deactivate it one byte time after transmission. While the receiver is active the flag detect pin is pulsed each time a flag sequence is detected in the receive data stream. Following an 8273 reset, all pins of Port B are set to a high, inactive level.

The user defined output bits correspond to the state of PB_4-PB_1 pins. The 8273 does not interrogate or manipulate these bits.

Serial Data Logic

The Serial data is synchronized by the user transmit ($\overline{TxC}$) and receive ($\overline{RxC}$) clocks. The leading edge of $\overline{TxC}$ generates new transmit data and the trailing edge of $\overline{RxC}$ is used to capture receive data. The NRZI encoding/decoding of the receive and transmit data is programmable.

The diagnostic features included in the Serial Data logic are programmable loop back of data and selectable clock for the receiver. In the loop-back mode, the data presented to the TxD pin is internally routed to the receive data input circuitry in place of the RxD pin, thus allowing a CPU to send a message to itself to verify operation of the 8273.

In the selectable clock diagnostic feature, when the data is looped back, the receiver may be presented incorrect sample timing by the external circuitry. The user may select to substitute the $\overline{TxC}$ pin for the $\overline{RxC}$ input on-chip so that the clock used to generate the loop back data is used to sample it. Since TxD is generated off the leading edge of $\overline{TxC}$ and RxD is sampled on the trailing edge, the selected clock allows bit synchronism.

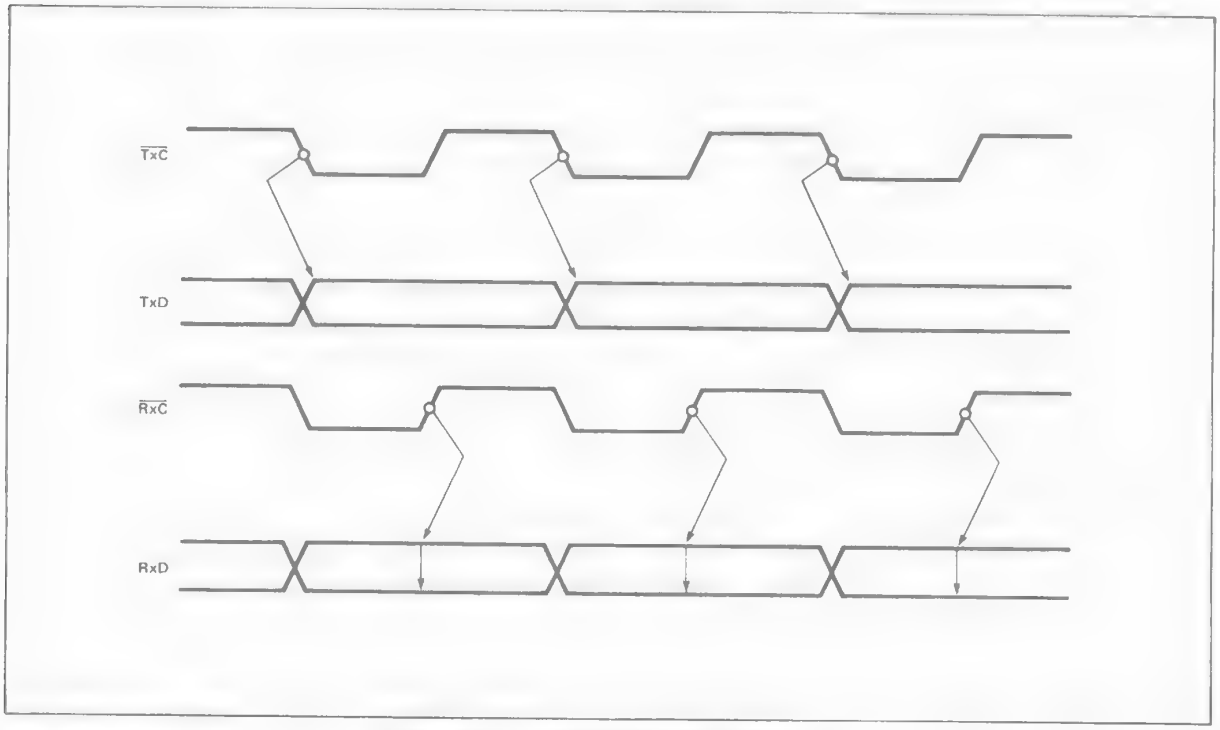


Figure 6. Transmit/Receive Timing

Asynchronous Mode Interface

Although the 8273 is fully compatible with the HDLC/SDLC communication line protocols, which are primarily designed for synchronous communication, the 8273 can also be used in asynchronous applications by using this interface. The interface employs a digital phase locked loop (DPLL) for clock recovery from a receive data stream and programmable NRZI encoding and decoding of data. The use of NRZI coding with SDLC transmission guarantees that within a frame, data transitions will occur at least every five bit times — the longest sequence of ones which may be transmitted without zero-bit insertion. The DPLL should be used only when NRZI coding is used since the NRZI coding will transmit zero sequence as line transitions. The digital phase locked loop also facilitates full-duplex and half-duplex asynchronous implementation with, or without modems.

Digital Phase Locked Loop

In asynchronous applications, the clock is derived from the receiver data stream by the use of the digital phase locked loop (DPLL). The DPLL requires a clock input at 32 times the required baud rate. The receive data (RxD) is sampled with this $\overline{32X\ CLK}$ and the 8273 DPLL supplies a sample pulse nominally centered on the RxD bit cells. The DPLL has a built-in "stiffness" which reduces sensitivity to line noise and bit distortion. This is accomplished by making phase error adjustments in discrete increments. Since the nominal pulse is made to occur at 32 counts of the $\overline{32X\ CLK}$, these counts are subtracted or added to the nominal, depending upon which quadrant of the four error quadrants the data edge occurs in. For example if an RxD edge is detected in quadrant A1, it is apparent that the $\overline{DPLL}$ sample "A" was placed too close to the trailing edge of the data cell; sample "B" will then be placed at T = ($T_{nominal}$ - 2 counts) = 30 counts of the $\overline{32X\ CLK}$ to move the sample pulse "B" toward the nominal center of the next bit cell. A data edge occuring in quadrant B1 would cause a smaller adjustment of phase with T = 31 counts of the $\overline{32X\ CLK}$. Using this technique the $\overline{DPLL}$ pulse will converge to nominal bit center within 12 data bit times, worst case, with constant incoming RxD edges.

A method of attaining bit synchronism following a line idle is to use PRE-FRAME SYNC mode of transmission.

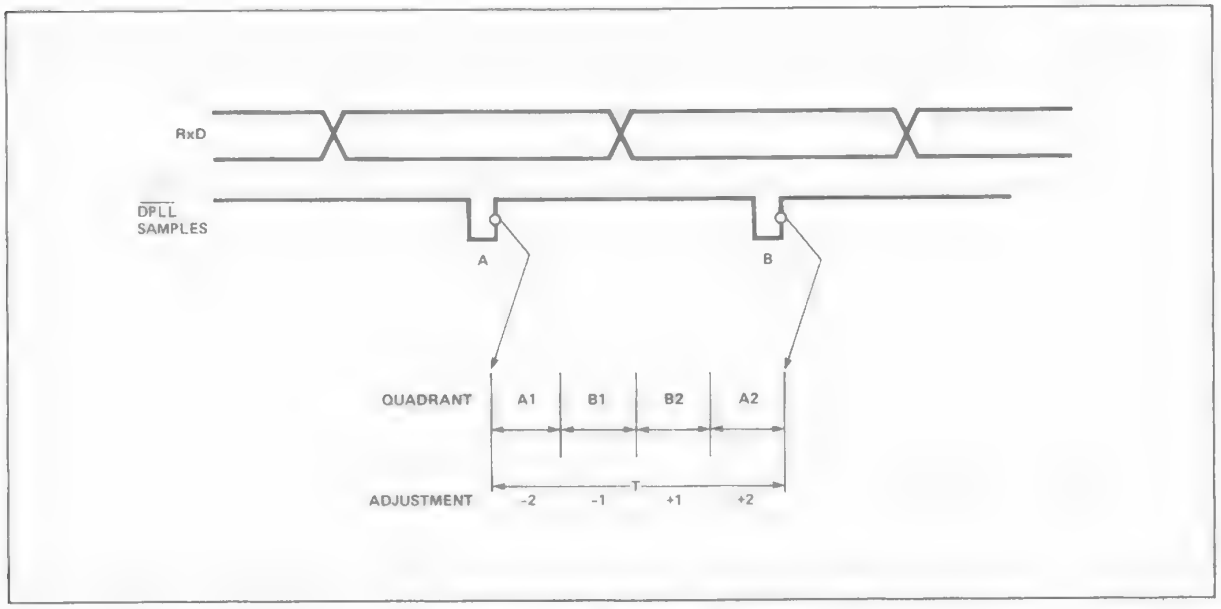
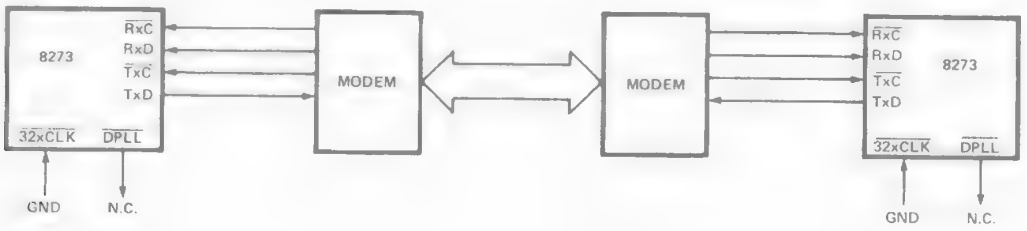
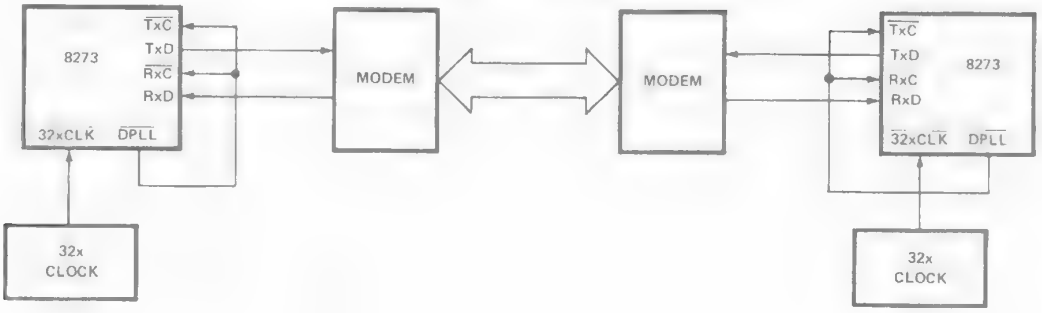


Figure 7. DPLL Sample Timing

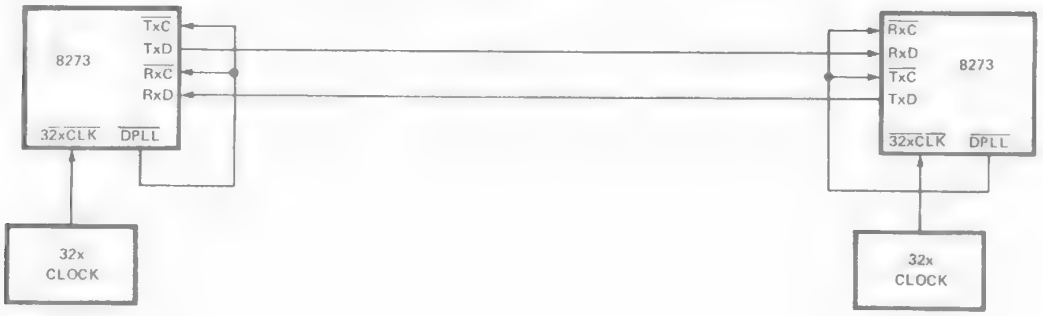
Synchronous Modem — Duplex or Half Duplex Operation



Asynchronous Modems — Duplex or Half Duplex Operation



Asynchronous — No Modems — Duplex or Half Duplex



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SDLC Loop

The DPLL simplifies the SDLC loop station implementation. In this application, each secondary station on a loop data link is a repeater set in one-bit delay mode. The signals sent out on the loop by the loop controller (primary station) are relayed from station to station then, back to the controller. Any secondary station finding its address in the A field captures the frame for action at that station. All received frames are relayed to the next station on the loop.

Loop stations are required to derive bit timing from the incoming NRZI data stream. The DPLL generates sample Rx clock timing for reception and uses the same clock to implement Tx clock timing.

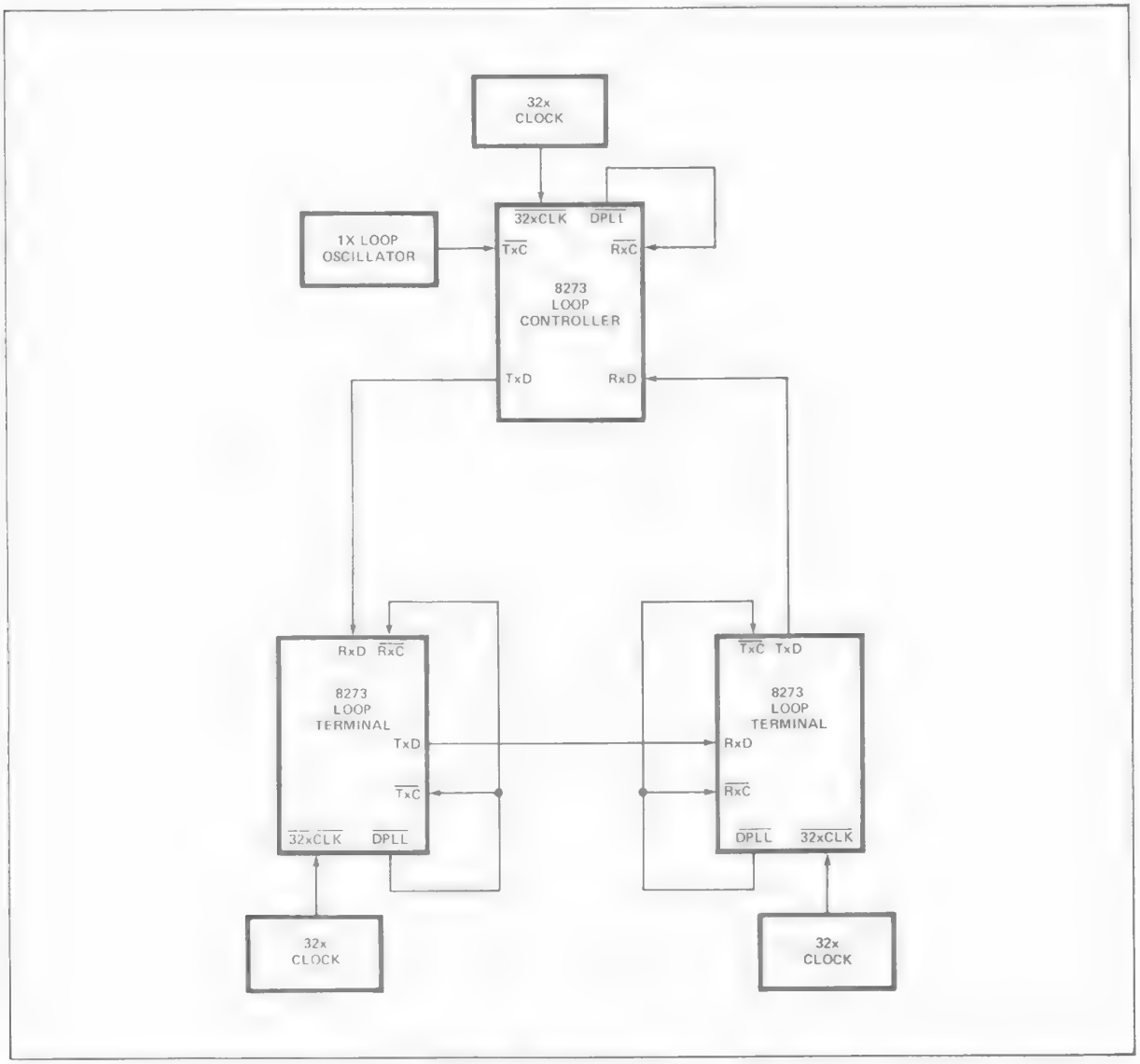

Figure 8. SDLC Loop Application

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PRINCIPLES OF OPERATION

The 8273 is an intelligent peripheral controller which relieves the CPU of many of the rote tasks associated with constructing and receiving frames. It is fully compatible with the MCS-80/85™ system bus. As a peripheral device, it accepts commands from a CPU, executes these commands and provides an Interrupt and Result back to the CPU at the end of the execution. The communication with the CPU is done by activation of $\overline{CS}$, $\overline{RD}$, $\overline{WR}$ pins, while the A_1, A_0 select the appropriate registers on the chip as described in the Hardware Description Section.

The 8273 operation is composed of the following sequence of events:

COMMAND PHASE	CPU WRITES COMMAND AND PARAMETERS INTO THE 8273 COMMAND AND PARAMETER REGISTERS
EXECUTION PHASE	THE 8273 IS ON ITS OWN TO CARRY OUT THE COMMAND.
RESULT PHASE	THE 8273 SIGNALS THE CPU THAT THE EXECUTION HAS FINISHED. THE CPU MUST PERFORM A READ OPERATION OF ONE OR MORE OF THE REGISTERS.

The Command Phase

During the command phase, the software writes a command to the command register. The command bytes provide a general description of the type of operation requested. Many commands require more detailed information about the command. In such a case up to four parameters are written into the parameter register. The flowchart of the command phase indicates that a command may not be issued if the Status Register indicates that the device is busy. Similarly if a parameter is issued when the Parameter Buffer shows full, incorrect operation will occur.

The 8273 is a duplex device and both transmitter and receiver may each be executing a command or passing results at any given time. For this reason separate interrupt pins are provided. However, the command register must be used for one command sequence at a time.

Status Register

The status register contains the status of the 8273 activity. The description is as follows.

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CBSY	CBF	CPBF	CRBF	RxINT	TxINT	RxIRA	TxIRA

Bit 7 CBSY (Command Busy)

Indicates in-progress command, set for CPU poll when Command Register is full, reset upon command phase completion. It is improper to write a command when CBSY is set; it results in incorrect operation.

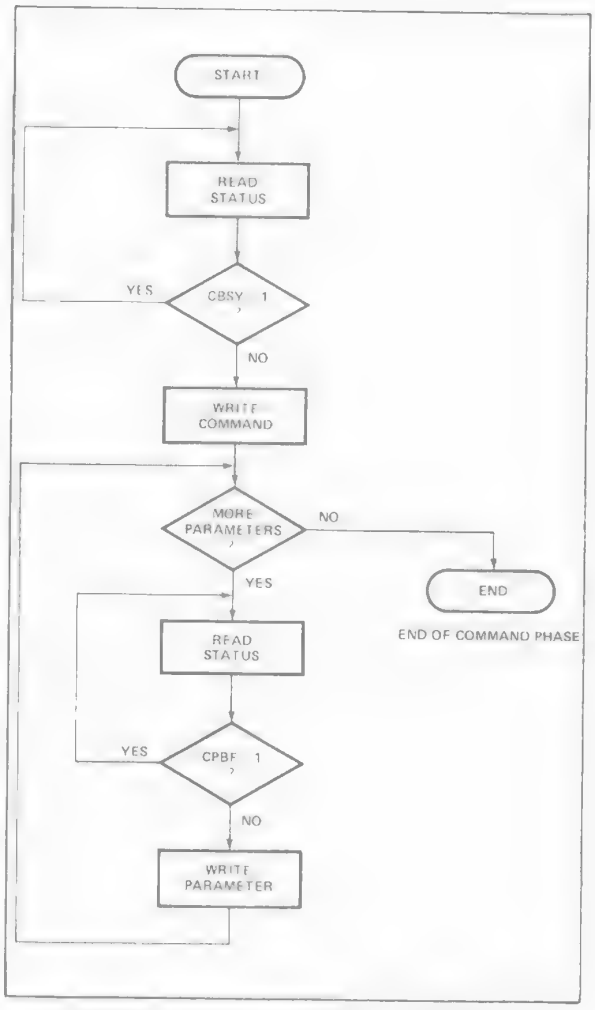

Figure 9. Command Phase Flowchart

Bit 6 CBF (Command Buffer Full)

Indicates that the command register is full, it is reset when the 8273 accepts the command byte but does not imply that execution has begun.

Bit 5 CPBF (Command Parameter Buffer Full)

CPBF is set when the parameter buffer is full, and is reset by the 8273 when it accepts the parameter. The CPU may poll CPBF to determine when additional parameters may be written.

Bit 4 CRBF (Command Result Buffer Full)

Indicates that an executed command immediate result is present in the Result Register. It is set by 8273 and reset when CPU reads the result.

Bit 3 RxINT (Receiver Interrupt)

RxINT indicates that the receiver requires CPU attention. It is identical to RxINT (pin 11) and is set by the 8273 either upon good/bad completion of a specified command or by Non-DMA data transfer. It is reset only after the CPU has read the result byte or has received a data byte from the 8273 in a Non-DMA data transfer.

Bit 2 TxINT (Transmitter Interrupt)

The TxINT indicates that the transmitter requires CPU attention. It is identical to TxINT (pin 2). It is set by 8273 either upon good/bad completion of a specified command or by Non-DMA data transfer. It is reset only after the CPU has read the result byte or has transferred transmit data byte to the 8273 in a Non-DMA transfer.

Bit 1 RxIRA (Receiver Interrupt Result Available)

The RxIRA is set by the 8273 when an interrupt result byte is placed in the RxINT register. It is reset after the CPU has read the RxINT register.

Bit 0 TxIRA (Transmitter Interrupt Result Available)

The TxIRA is set by the 8273 when an interrupt result byte is placed in the TxINT register. It is reset when the CPU has read the TxINT register.

The Execution Phase

Upon accepting the last parameter, the 8273 enters into the Execution Phase. The execution phase may consist of a DMA or other activity, and may or may not require CPU intervention. The CPU intervention is eliminated in this phase if the system utilizes DMA for the data transfers, otherwise, for non-DMA data transfers, the CPU is interrupted by the 8273 via TxINT and RxINT pins, for each data byte request.

The Result Phase

During the result phase, the 8273 notifies the CPU of the execution outcome of a command. This phase is initiated by:

1. The successful completion of an operation
2. An error detected during an operation.

To facilitate quick network software decisions, two types of execution results are provided:

1. An Immediate Result
2. A Non-Immediate Result

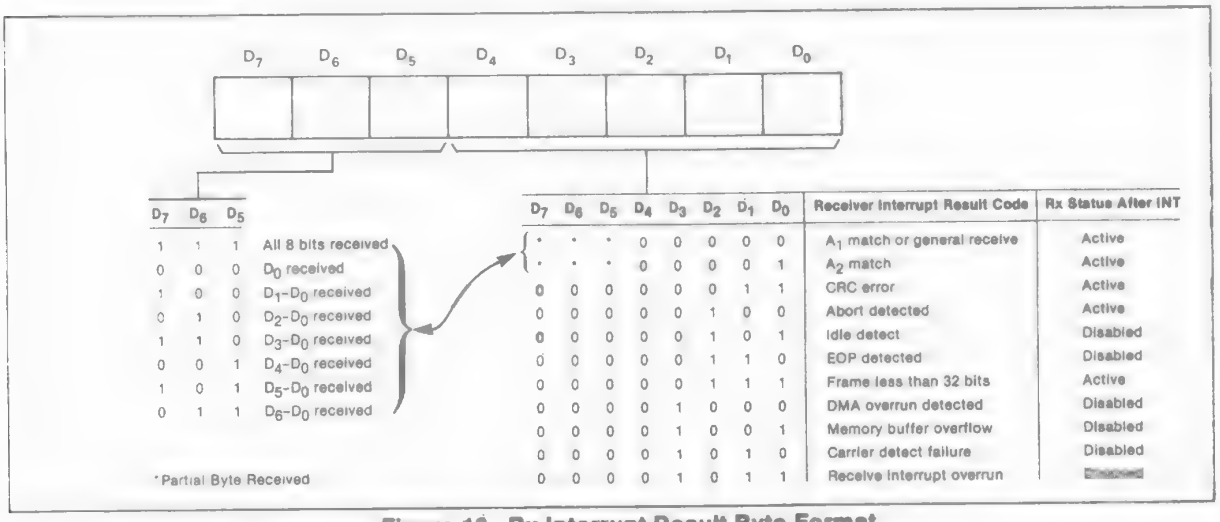

Figure 10. Rx Interrupt Result Byte Format

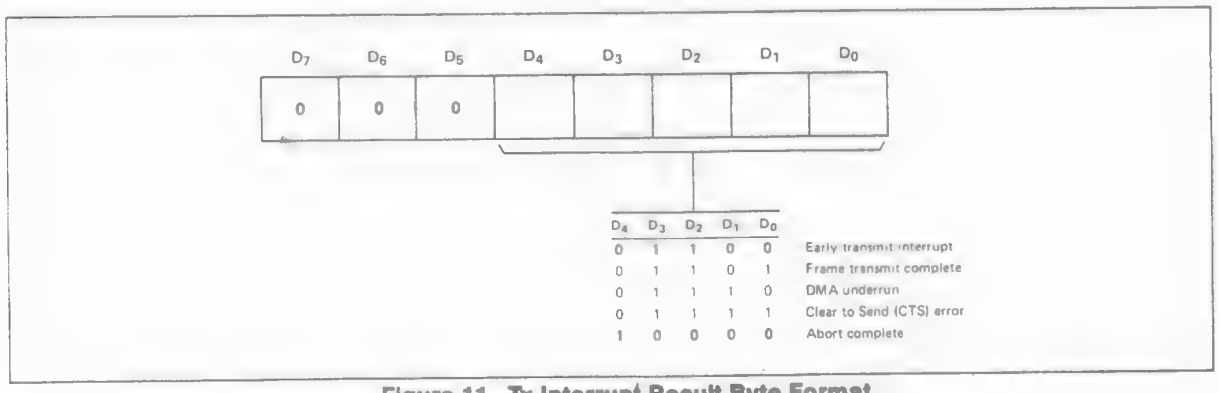

Figure 11. Tx Interrupt Result Byte Format

Immediate result is provided by the 8273 for commands such as Read Port A and Read Port B which have information ($\overline{CTS}$, $\overline{CD}$, $\overline{RTS}$, etc.) that the network software needs to make quick operational decisions.

A command which cannot provide an immediate result will generate an interrupt to signal the beginning of the Result phase. The immediate results are provided in the Result Register; all non-immediate results are available upon device interrupt, through Tx Interrupt Result Register TxI/R or Rx Interrupt Result Register RxI/R. The result may consist of a one-byte interrupt code indicating the condition for the interrupt and, if required, one or more bytes which detail the condition.

Tx and Rx Interrupt Result Registers

The Result Registers have a result code, the three high order bits D_7-D_5 of which are set to zero for all but the receive command. This command result contains a count that indicates the number of bits received in the last byte. If a partial byte is received, the high order bits of the last data byte are indeterminate.

All results indicated in the command summary must be read during the result phase.

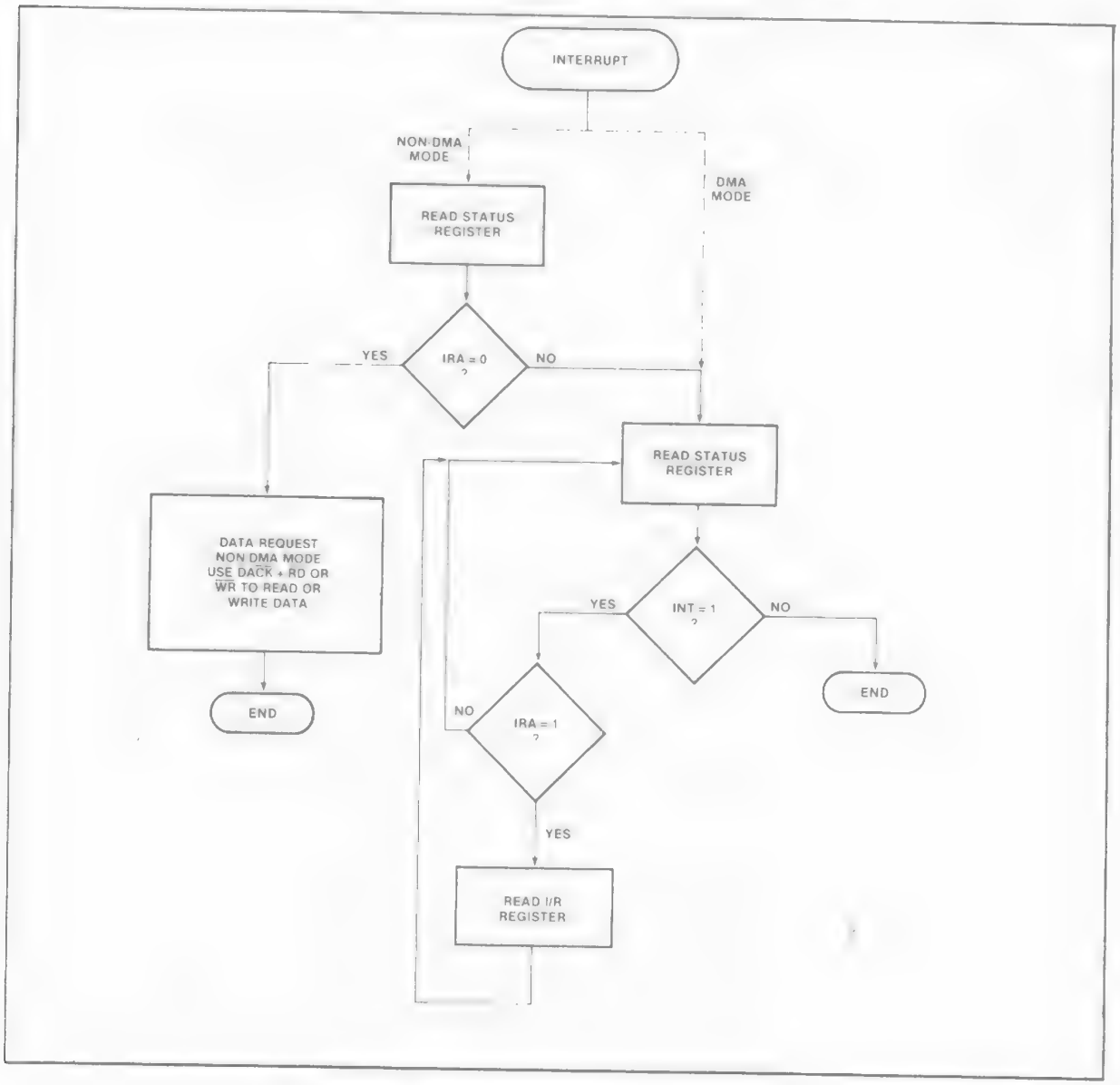

Figure 12. Result Phase Flowchart—Interrupt Results

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IMMEDIATE RESULTS

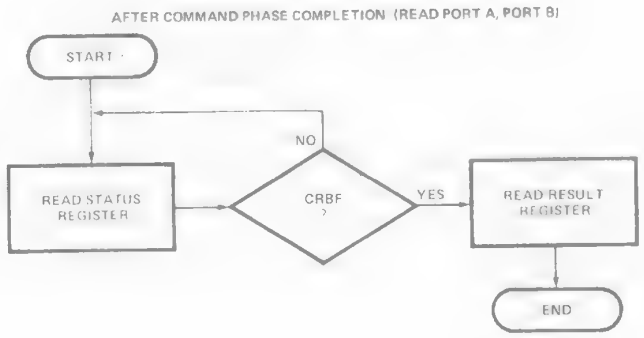

Figure 13. (Rx Interrupt Service)

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DETAILED COMMAND DESCRIPTION

General

The 8273 HDLC/SDLC controller supports a comprehensive set of high level commands which allows the 8273 to be readily used in full-duplex, half-duplex, synchronous, asynchronous and SDLC loop configuration, with or without modems. These frame-level commands minimize CPU and software overhead. The 8273 has address and control byte buffers which allow the receive and transmit commands to be used in buffered or non-buffered modes.

In buffered transmit mode, the 8273 transmits a flag automatically, reads the Address and Control buffer registers and transmits the fields, then via DMA, it fetches the information field. The 8273, having transmitted the information field, automatically appends the Frame Check Sequence (FCS) and the end flag. Correspondingly, in buffered read mode, the Address and Control fields are stored in their respective buffer registers and only Information Field is transferred to memory.

In non-buffered transmit mode, the 8273 transmits the beginning flag automatically, then fetches and transmits the Address, Control and Information fields from the memory, appends the FCS character and an end flag. In the non-buffered receive mode the entire contents of a frame are sent to memory with the exception of the flags and FCS.

HDLC Implemenation

HDLC Address and Control field are extendable. The extension is selected by setting the low order bit of the field to be extended to a one, a zero in the low order bit indicates the last byte of the respective field.

Since Address/Control field extension is normally done with software to maximize extension flexibility, the 8273 does not create or operate upon contents of the extended HDLC Address/Control fields. Extended fields are transparently passed by the 8273 to user as either interrupt results or data transfer requests. Software must assemble the fields for transmission and interrogate them upon reception.

However, the user can take advantage of the powerful 8273 commands to minimize CPU/Software overhead and simplify buffer management in handling extended fields: For instance buffered mode can be used to separate the first two bytes, then interrogate the others from buffer. Buffered mode is perfect for a two byte address field.

The 8273 when programmed, recognizes protocol characters unique to HDLC such as Abort, which is a string of seven or more ones (01111111). Since Abort character is the same as the GA (EOP) character used in SDLC Loop applications, Loop Transmit and Receive commands are not recommended to be used in HDLC. HDLC does not support Loop mode.

Initialization Set/Reset Commands

These commands are used to manipulate data within the 8273 registers. The Set commands have a single parameter which is a mask that corresponds to the bits to be set. (They perform a logical-OR of the specified register with the mask provided as a parameter). The Register commands have a single parameter which is a mask that has a zero in the bit positions that are to be reset. (They perform a logical-AND of the specified register with the mask).

Set One-Bit Delay (CMD Code A4)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	0	1	0	0	1	0	0
PAR:	0	1	1	0	0	0	0	0	0	0

When one bit delay is set, 8273 retransmits the received data stream one bit delayed. This mode is entered at a receiver character boundary, and should only be used by Loop Stations.

Reset One-Bit Delay (CMD Code 64)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	0	1	1	0	0	1	0	0
PAR:	0	1	0	1	1	1	1	1	1	1

The 8273 stops the one bit delayed retransmission mode.

Set Data Transfer Mode (CMD Code 97)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	0	0	1	0	1	1	1
PAR:	0	1	0	0	0	0	0	0	0	1

When the data transfer mode is set, the 8273 will interrupt when data bytes are required for transmission or are available from a receive. If a transmit interrupt occurs and the status indicates that there is no Transmit Result (TxIRA = 0), the interrupt is a transmit data request. If a receive interrupt occurs and the status indicates that there is no receive result (RxIRA = 0), the interrupt is a receive data request.

Reset Data Transfer Mode (CMD Code 57)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	0	1	0	1	0	1	1	1
PAR	0	1	1	1	1	1	1	1	1	0

If the Data Transfer Mode is reset, the 8273 data transfers are performed through the DMA requests without interrupting the CPU.

Set Operating Mode (CMD Code 91)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	0	0	1	0	0	0	1
PAR:	0	1	0	0						

1 = FLAG STREAM MODE
1 = PREFRAME SYNC MODE
1 = BUFFERED MODE
1 = EARLY INTERRUPT MODE
1 = EOP INTERRUPT MODE
1 = HDLC MODE

Reset Operating Mode (CMD Code 51)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	0	1	0	1	0	0	0	1
PAR:	0	1	1	1						

Any mode switches set in CMD code 91 can be reset using this command by placing zeros in the appropriate positions.

(D5) HDLC Mode

In HDLC mode, a bit sequence of seven ones (01111111) is interpreted as an abort character. Otherwise, eight ones (011111111) signal an abort.

(D4) EOP Interrupt Mode

In EOP interrupt mode, an interrupt is generated whenever an EOP character (01111111) is detected by an active receiver. This mode is useful for the implementation of an SDLC loop controller in detecting the end of a message stream after a loop poll.

(D3) Transmitter Early Interrupt Mode (Tx)

The early interrupt mode is specified to indicate when the 8273 should generate an end of frame interrupt. When set, an early interrupt is generated when the last data character has been passed to the 8273. If the user software responds with another transmit command before the final flag is sent, the final flag interrupt will not be generated and a new frame will immediately begin when the current frame is complete. This permits frames to be separated by a single flag. If no additional Tx commands are provided, a final interrupt will follow.

Note: In buffered mode, if a supervisory frame (no Information) Transmit command is sent in response to an early Transmit Interrupt, the 8273 will repeatedly transmit the same supervisory frame with one flag in between, until a non-supervisory transmit is issued.

Early transmitter interrupt can be used in buffered mode by waiting for a transmit complete interrupt instead of early Transmit Interrupt before issuing a transmit frame command for a supervisory frame. See Figure 14.

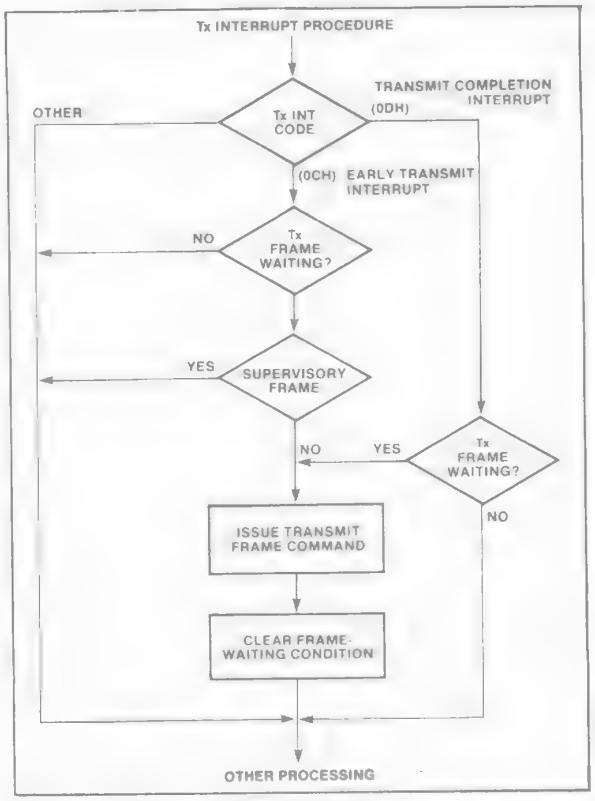

Figure 14.

If this bit is zero, the interrupt will be generated only after the final flag has been transmitted.

(D2) Buffered Mode

If the buffered mode bit is set to a one, the first two bytes (normally the address (A) and control (C) fields) of a frame are buffered by the 8273. If this bit is a zero the address and control fields are passed to and from memory.

(D1) Preframe Sync Mode

If this bit is set to a one the 8273 will transmit two characters before the first flag of a frame.
To guarantee sixteen line transitions, the 8273 sends two bytes of data $(00)_H$ if NRZI is set or data $(55)_H$ if NRZI is not set.

(D0) Flag Stream Mode

If this bit is set to a one, the following table outlines the operation of the transmitter.

TRANSMITTER STATE	ACTION
Idle	Send Flags immediately.
Transmit or Transmit-Transparent Active	Send Flags after the transmission complete
Loop Transmit Active	Ignore command.
1 Bit Delay Active	Ignore command.

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If this bit is reset to zero the following table outlines the operation of the transmitter.

TRANSMITTER STATE	ACTION
IDLE	Send Idles on next character boundary.
Transmit or Transmit Transparent Active	Send Idles after the transmission is complete.
Loop Transmit Active	Ignore command.
1 Bit Delay Active	Ignore command.

Set Serial I/O Mode (CMD Code A0)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	0	1	0	0	0	0	0
PAR:	0	1	0	0	0	0	0			

1 = NRZ1 MODE

1 = TxC → RxC

1 = LOOP BACK TxD → RxD

Reset Serial I/O Mode (CMD Code 60)

This command allows bits set in CMD code A0 to be reset by placing zeros in the appropriate positions.

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	0	1	1	0	0	0	0	0
PAR:	0	1	1	1	1	1	1			

(D2) Loop Back

If this bit is set to a one, the transmit data is internally routed to the receive data circuitry.

(D1) TxC → RxC

If this bit is set to a one, the transmit clock is internally routed to the receive clock circuitry. It is normally used with the loop back bit (D2).

(D0) NRZI Mode

If this bit is set to a one, NRZI encoding and decoding of transmit and receive data is provided. If this bit is a zero, the transmit and receive data is treated as a normal positive logic bit stream.

NRZI encoding specifies that a zero causes a change in the polarity of the transmitted signal and a one causes no polarity change. NRZI is used in all asynchronous operations Refer to IBM document GA27-3093 for details.

Reset Device Command

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
TMR:	1	0	0	0	0	0	0	0	0	1
TMR:	1	0	0	0	0	0	0	0	0	0

An 8273 reset command is executed by outputing a $(01)_H$ followed by $(00)_H$ to the reset register (TMR). See 8273 AC timing characteristics for Reset pulse specifications.

The reset command emulates the action of the reset pin.

1. The modem control signals are forced high (inactive level).
2. The 8273 status register flags are cleared.
3. Any commands in progress are terminated immediately.
4. The 8273 enters an idle state until the next command is issued.
5. The Serial I/O and Operating Mode registers are set to zero and DMA data register transfer mode is selected.
6. The device assumes a non-loop SDLC terminal role.

Receive Commands

The 8273 supports three receive commands: General Receive, Selective Receive, and Selective Loop Receive.

General Receive (CMD Code C0)

General receive is a receive mode in which frames are received regardless of the contents of the address field.

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	1	0	0	0	0	0	0
PAR	0	1	LEAST SIGNIFICANT BYTE OF THE RECEIVE BUFFER LENGTH (B0)							
PAR	0	1	MOST SIGNIFICANT BYTE OF RECEIVE BUFFER LENGTH (B1)							

NOTES:

1. If buffered mode is specified, the R0, R1 receive frame length (result) is the number of data bytes received.
2. If non-buffered mode is specified, the R0, R1 receive frame length (result) is the number of data bytes received plus two (the count includes the address and control bytes).
3. The frame check sequence (FCS) is not transferred to memory.
4. Frames with less than 32 bits between flags are ignored (no interrupt generated) if the buffered mode is specified.
5. In the non-buffered mode an interrupt is generated when a less than 32 bit frame is received, since data transfer requests have occurred.
6. The 8273 receiver is always disabled when an Idle is received after a valid frame. The CPU module must issue a receive command to re-enable the receiver.
7. The intervening ABORT character between a final flag and an IDLE does not generate an interrupt
8. If an ABORT Character is not preceded by a flag and is followed by an IDLE, an interrupt will be generated for the ABORT followed by an IDLE interrupt one character time later. The reception of an ABORT will disable the receiver

Selective Receive (CMD Code C1)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	1	0	0	0	0	0	1
PAR	0	1	LEAST SIGNIFICANT BYTE OF THE RECEIVE BUFFER LENGTH (B0)							
PAR:	0	1	MOST SIGNIFICANT BYTE OF RECEIVE BUFFER LENGTH (B1)							
PAR	0	1	RECEIVE FRAME ADDRESS MATCH FIELD ONE (A1)							
PAR:	0	1	RECEIVE FRAME ADDRESS MATCH FIELD TWO (A2)							

Selective receive is a receive mode in which frames are ignored unless the address field matches any one of two address fields given to the 8273 as parameters.

When selective receive is used in HDLC the 8273 looks at the first character, if extended, software must then decide if the message is for this unit.

Selective Loop Receive (CMD Code C2)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	1	0	0	0	0	1	0
PAR:	0	0	LEAST SIGNIFICANT BYTE OF THE RECEIVE BUFFER LENGTH (B0)							
PAR:	0	1	MOST SIGNIFICANT BYTE OF RECEIVE BUFFER LENGTH (B1)							
PAR	0	1	RECEIVE FRAME ADDRESS MATCH FIELD ONE (A1)							
PAR:	0	1	RECEIVE FRAME ADDRESS MATCH FIELD TWO (A2)							

Selective loop receive operates like selective receive except that the transmitter is placed in flag stream mode automatically after detecting an EOP (01111111) following a valid received frame. The one bit delay mode is also reset at the end of a selective loop receive.

Receive Disable (CMD Code C5)

Terminates an active receive command immediately.

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	1	0	0	0	1	0	1
PAR	NONE									

Transmit Commands

The 8273 supports three transmit commands: Transmit Frame, Loop Transmit, Transmit Transparent.

Transmit Frame (CMD Code C8)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	1	0	0	1	0	0	0
PAR:	0	1	LEAST SIGNIFICANT BYTE OF FRAME LENGTH (L0)							
PAR:	0	1	MOST SIGNIFICANT BYTE OF FRAME LENGTH (L1)							
PAR:	0	1	ADDRESS FIELD OF TRANSMIT FRAME (A)							
PAR:	0	1	CONTROL FIELD OF TRANSMIT FRAME (C)							

Transmits one frame including: initial flag, frame check sequence, and the final flag.

If the buffered mode is specified, the L0, L1, frame length provided as a parameter is the length of the information field and the address and control fields must be input.

In unbuffered mode the frame length provided must be the length of the information field plus two and the address and control fields must be the first two bytes of data. Thus only the frame length bytes are required as parameters.

Loop Transmit (CMD Code CA)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	1	0	0	1	0	1	0
PAR:	0	1	LEAST SIGNIFICANT BYTE OF FRAME LENGTH (L0)							
PAR:	0	1	MOST SIGNIFICANT BYTE OF FRAME LENGTH (L1)							
PAR:	0	1	ADDRESS FIELD OF TRANSMIT FRAME (A)							
PAR:	0	1	CONTROL FIELD OF TRANSMIT FRAME (C)							

Transmits one frame in the same manner as the transmit frame command except:

1. If the flag stream mode is not active transmission will begin after a received EOP has been converted to a flag.
2. If the flag stream mode is active transmission will begin at the next flag boundary for buffered mode or at the third flag boundary for non-buffered mode.
3. At the end of a loop transmit the one-bit delay mode is entered and the flag stream mode is reset.

Transmit Transparent (CMD Coded C9)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	1	0	0	1	0	0	1
PAR	0	1	LEAST SIGNIFICANT BYTE OF FRAME LENGTH (L0)							
PAR.	0	1	MOST SIGNIFICANT BYTE OF FRAME LENGTH (L1)							

The 8273 will transmit a block of raw data without protocol, i.e., no zero bit insertion, flags, or frame check sequences.

Abort Transmit Commands

An abort command is supported for each type of transmit command. The abort commands are ignored if a transmit command is not in progress.

Abort Transmit Frame (CMD Code CC)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	1	0	0	1	1	0	0
PAR	NONE									

After an abort character (eight contiguous ones) is transmitted, the transmitter reverts to sending flags or idles as a function of the flag stream mode specified.

Abort Loop Transmit (CMD Code CE)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD	0	0	1	1	0	0	1	1	1	0
PAR	NONE									

After a flag is transmitted the transmitter reverts to one bit delay mode.

Abort Transmit Transparent (CMD Code CD)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	1	0	0	1	1	0	1
PAR	NONE									

The transmitter reverts to sending flags or idles as a function of the flag stream mode specified.

Modem Control Commands

The modem control commands are used to manipulate the modem control ports.

When read Port A or Port B commands are executed the result of the command is returned in the result register. The Bit Set Port B command requires a parameter that is a mask that corresponds to the bits to be set. The Bit Reset Port B command requires a mask that has a zero in the bit positions that are to be reset.

Read Port A (CMD Code 22)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD	0	0	0	0	1	0	0	0	1	0

PAR. NONE

Read Port B (CMD Code 23)

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	0	0	1	0	0	0	1	1

PAR NONE

Set Port B Bits (CMD Code A3)

This command allows user defined Port B pins to be set.

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD:	0	0	1	0	1	0	0	0	1	1
PAR:	0	1	0	0						

RTS – REQUEST TO SEND

USER DEFINED

FLAG DETECT

(D_5) Flag Detect

This bit can be used to set the flag detect pin. However, it will be reset when the next flag is detected.

(D_4-D_1) User Defined Outputs

These bits correspond to the state of the PB_4-PB_1 output pins.

(D_0) Request to Send

This is a dedicated 8273 modem control signal, and reflects the same logical state of RTS pin.

Reset Port B Bits (CMD Code 63)

This command allows Port B user defined bits to be reset.

	A_1	A_0	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
CMD.	0	0	0	1	1	0	0	0	1	1
PAR	0	1	1	1						

RTS – REQUEST TO SEND

USER DEFINED

FLAG DETECT

This command allows Port B (D_4-D_1) user defined bits to be reset. These bits correspond to Output Port pins (PB_4-PB_1).

8273 Command Summary

Command Description	Command (HEX)	Parameter	Results	Result Port	Completion Interrupt
Set One Bit Delay	A4	Set Mask	None	—	No
Reset One Bit Delay	64	Reset Mask	None	—	No
Set Data Transfer Mode	97	Set Mask	None	—	No
Reset Data Transfer Mode	57	Reset Mask	None	—	No
Set Operating Mode	91	Set Mask	None	—	No
Reset Operating Mode	51	Reset Mask	None	—	No
Set Serial I/O Mode	A0	Set Mask	None	—	No
Reset Serial I/O Mode	60	Reset Mask	None	—	No
General Receive	C0	B0,B1	RIC,R0,R1,(A,C)(2)	RXI/R	Yes
Selective Receive	C1	B0,B1,A1,A2	RIC,R0,R1,(A,C)(2)	RXI/R	Yes
Selective Loop Receive	C2	B0,B1,A1,A2	RIC,R0,R1,(A,C)(2)	RXI/R	Yes
Receive Disable	C5	None	None	—	No
Transmit Frame	C8	L0,L1,(A,C)(1)	TIC	TXI/R	Yes
Loop Transmit	CA	L0,L1,(A,C)(1)	TIC	TXI/R	Yes
Transmit Transparent	C9	L0,L1	TIC	TXI/R	Yes
Abort Transmit Frame	CC	None	TIC	TXI/R	Yes
Abort Loop Transmit	CE	None	TIC	TXI/R	Yes
Abort Transmit Transparent	CD	None	TIC	TXI/R	Yes
Read Port A	22	None	Port Value	Result	No
Read Port B	23	None	Port Value	Result	No
Set Port B Bit	A3	Set Mask	None	—	No
Reset Port B Bit	63	Reset Mask	None	—	No

NOTES:
1. Issued only when in buffered mode.
2. Read as results only in buffered mode.

8273 Command Summary Key

B0 — Least significant byte of the receive buffer length.
B1 — Most significant byte of the receive buffer length.
L0 — Least significant byte of the Tx frame length.
L1 — Most significant byte of the Tx frame length.
A1 — Receive frame address match field one.
A2 — Receive frame address match field two.
A — Address field of received frame. If non-buffered mode is specified, this result is not provided.
C — Control field of received frame. If non-buffered mode is specified this result is not provided.
RXI/R — Receive interrupt result register.
TXI/R — Transmit interrupt result register.
R0 — Least significant byte of the length of the frame received.
R1 — Most significant byte of the length of the frame received.
RIC — Receiver interrupt result code.
TIC — Transmitter interrupt result code.

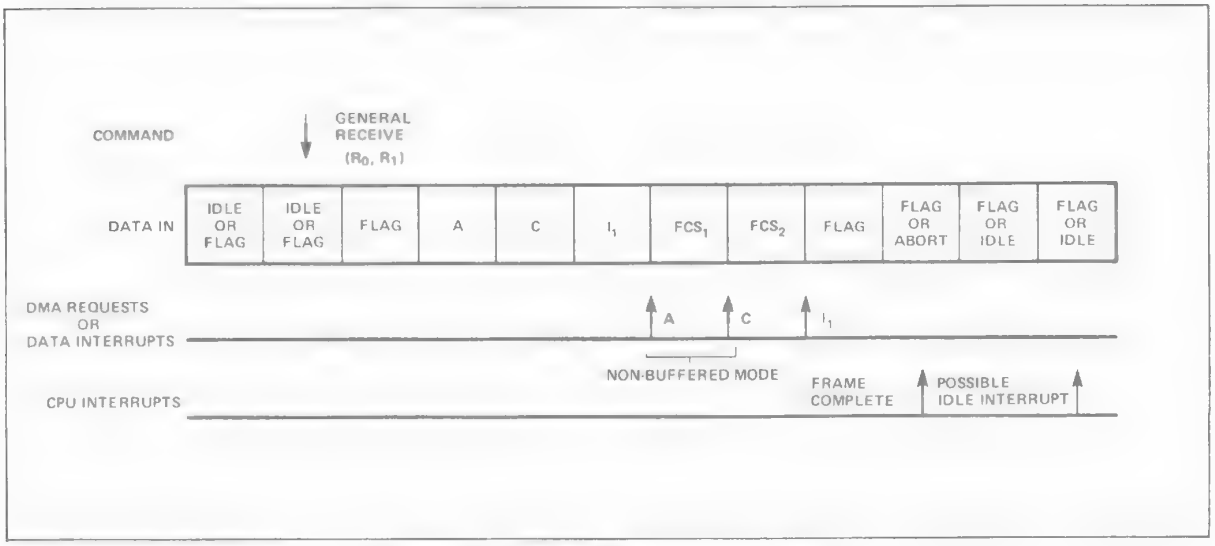

Figure 15. Typical Frame Reception

NOTE:
In order to ensure proper operation to the maximum baud rate, Receive commands or Read/Write Port commands should be written only when either the transmitter or the receiver is inactive. In full duplex systems, it is recommended that these commands be issued after servicing a transmitter interrupt but before a new transmit command is issued.

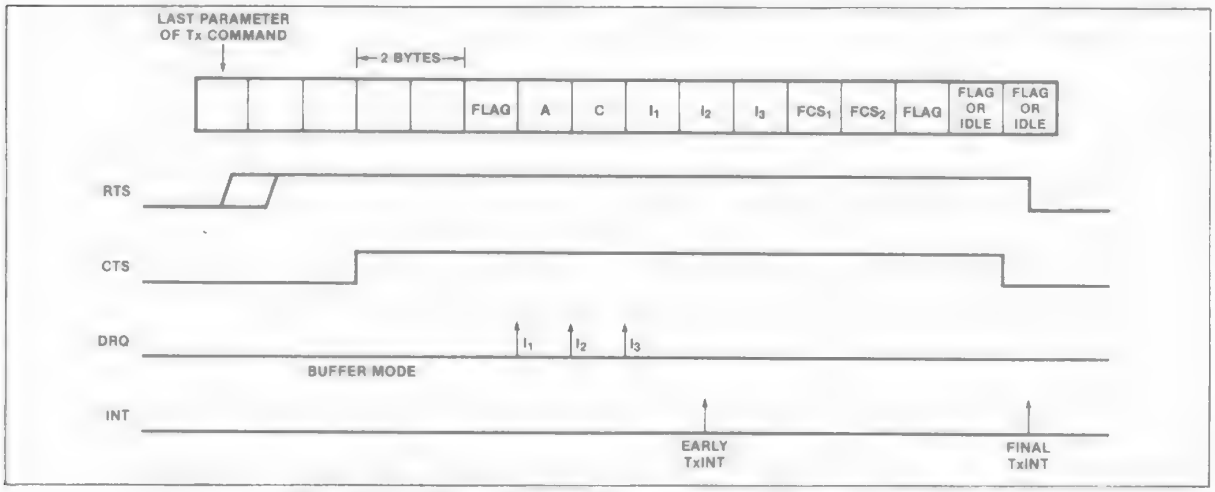

Figure 16a. Typical Frame Transmission, Buffered Mode

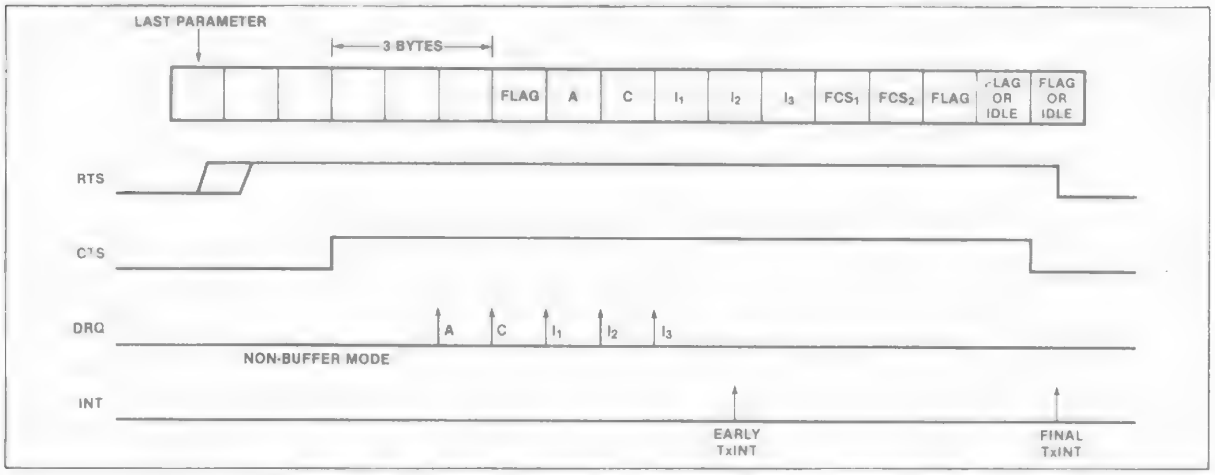

Figure 16b. Typical Frame Transmission, Non-Buffered Mode

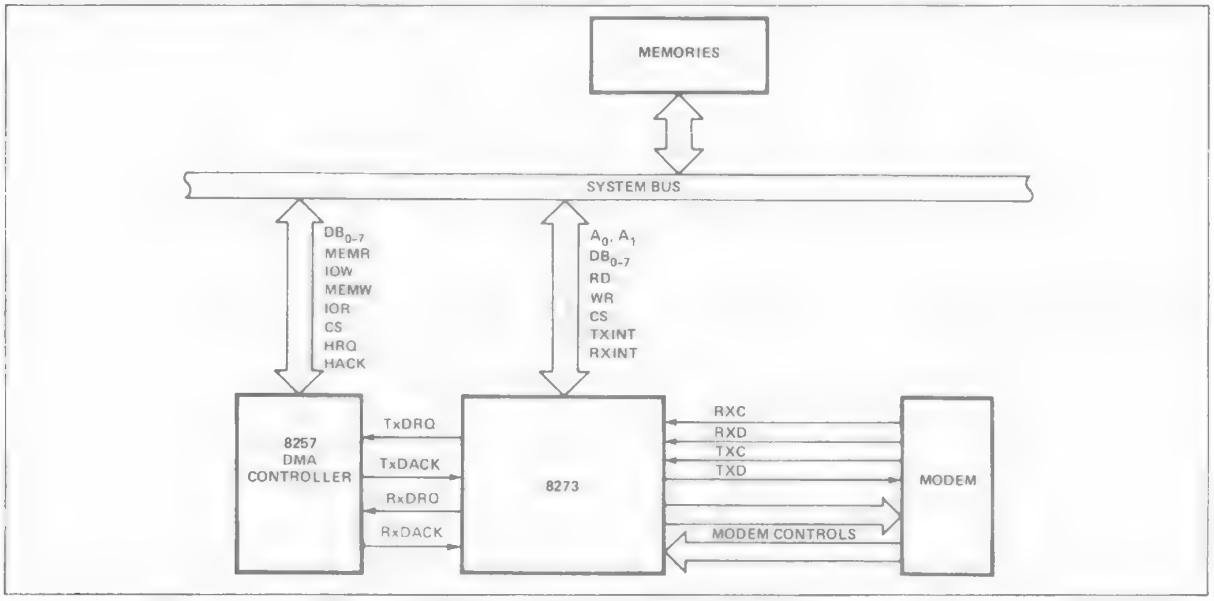

Figure 17. 8273 System Diagram

WAVEFORMS

COMMAND PHASE

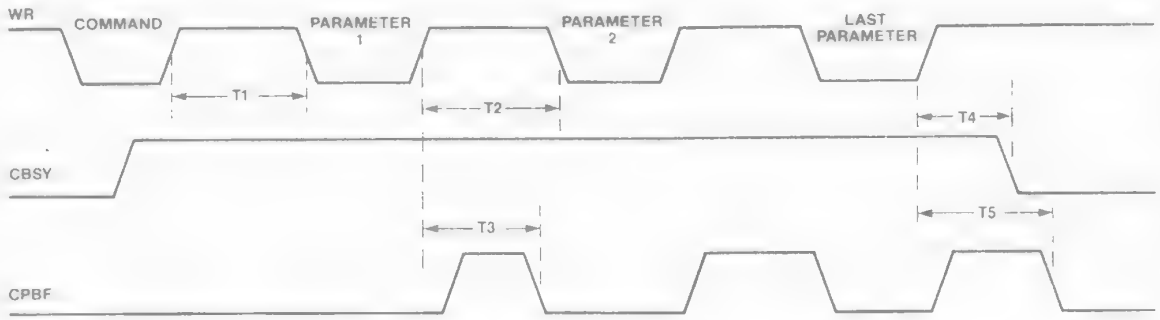

Table 2. Command Phase Timing (Full Duplex)

Symbol	Timing Parameter	Buffered		Non-Buffered		Unit
		Min.	Max.	Min.	Max.	
T1	Between command & first parameter	13	756	13	857	tcy
T2	Between consecutive parameters	10	604	10	705	tcy
T3	Command Parameter Buffer full bit Reset after Parameter loaded	10	604	10	705	tcy
T4	Command busy bit reset after last parameter	128	702	128	803	tcy
T5	CPBF bit reset after last parameter	10	604	10	705	tcy

WAVEFORMS (Continued)

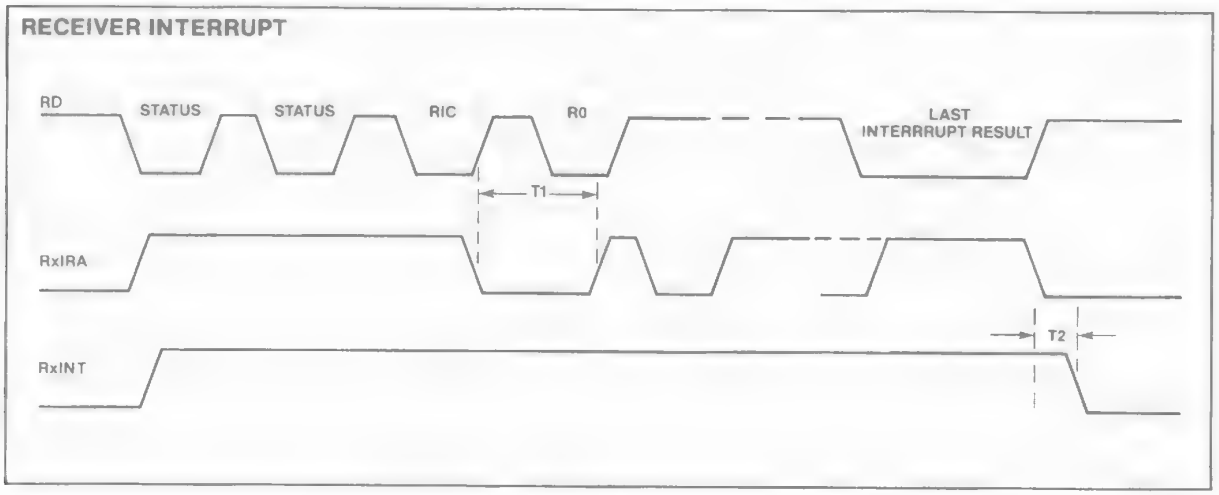

Table 3. Receiver Interrupt Result Timing

Symbol	Timing Parameter (clock cycles)	Buffered		Non-Buffered		Unit
		Min.	Max.	Min.	Max.	
T1	RxIRA bit set after RIC read	18	29	18	29	tcy
T2	RxINT goes away after last Int. Result read	16	27	16	27	tcy

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WAVEFORMS (Continued)

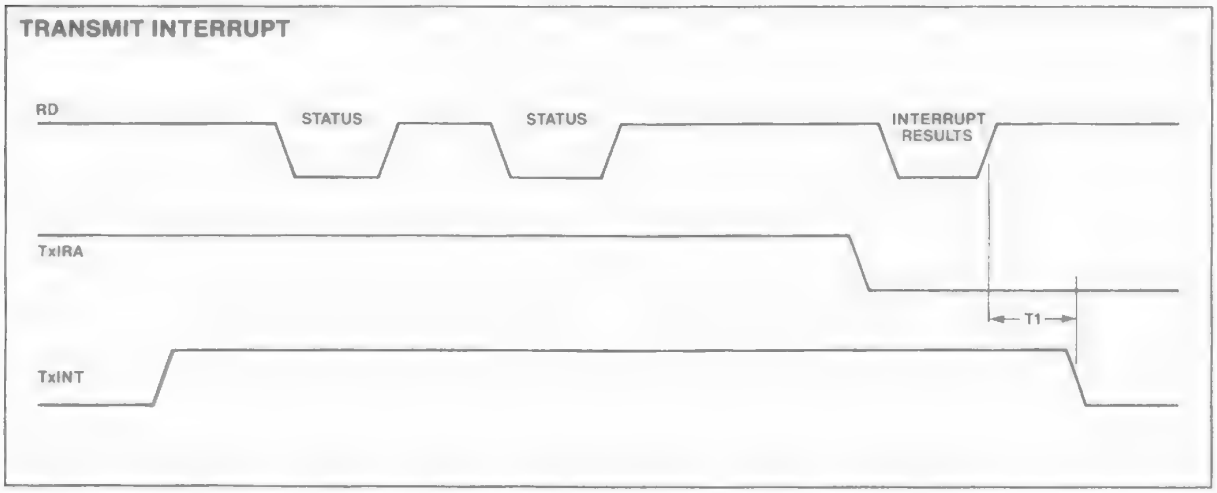


Table 4. Transmit Interrupt Result

Symbol	Timing (Clock Cycle)	Buffered		Non-Buffered		Unit
		Min.	Max.	Min.	Max.	
T1	TxINT inactive after Int. Results read	13	353	13	454	tcy

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... -65°C to +150°C
Voltage on Any Pin With Respect to Ground ..... -0.5V to +7V
Power Dissipation ..... 1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (8273, 8273-4, 8273-8) ($T_A = 0°C$ to $70°C$, $V_{CC} = +5.0V \pm 5\%$)

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_{IL}	Input Low Voltage	−0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	$V_{CC}+0.5$	V	
V_{OL}	Output Low Voltage		0.45	V	$I_{OL}=2.0$ mA for Data Bus Pins $I_{OL}=1.0$ mA for Output Port Pins $I_{OL}=1.6$ mA for All Other Pins
V_{OH}	Output High Voltage	2.4		V	$I_{OH}=-200\mu A$ for Data Bus Pins $I_{OH}=-100\mu A$ for All Other Pins
I_{IL}	Input Load Current		±10	μA	$V_{IN}=V_{CC}$ to 0V
I_{OFL}	Output Leakage Current		±10	μA	$V_{OUT}=V_{CC}$ to .45V
I_{CC}	V_{CC} Supply Current		180	mA	

CAPACITANCE (8273, 8273-4, 8273-8) ($T_A = 25°C$, $V_{CC} = GND = 0V$)

Symbol	Parameter	Min.	Typ.	Max.	Unit	Test Conditions
C_{IN}	Input Capacitance			10	pF	$t_c = 1$ MHz
$C_{I/O}$	I/O Capacitance			20	pF	Unmeasured Pins Returned to GND

A.C. CHARACTERISTICS ($T_A = 0°C$ to $70°C$, $V_{CC} = +5.0V \pm 5\%$)

CLOCK TIMING (8273)

Symbol	Parameter	Min.	Typ.	Max.	Unit	Test Conditions
t_{CY}	Clock	250		1000	ns	64K Baud Max Operating Rate
t_{CL}	Clock Low	120			ns	
t_{CH}	Clock High	120			ns	

CLOCK TIMING (8273-4)

Symbol	Parameter	Min.	Typ.	Max.	Unit	Test Conditions
t_{CY}	Clock	286		1000	ns	56K Baud Max Operating Rate
t_{CL}	Clock Low	135			ns	
t_{CH}	Clock High	135			ns	

CLOCK TIMING (8273-8)

Symbol	Parameter	Min.	Typ.	Max.	Unit	Test Conditions
t_{CY}	Clock	330		1000	ns	48K Baud Max Operating Rate
t_{CL}	Clock Low	150			ns	
t_{CH}	Clock High	150			ns	

A.C. CHARACTERISTICS (8273, 8273-4, 8273-8) (T_A = 0°C to 70°C, V_{CC} = +5.0V ±5%)

READ CYCLE

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AC}	Select Setup to $\overline{RD}$	0		ns	Note 2
t_{CA}	Select Hold from $\overline{RD}$	0		ns	Note 2
t_{RR}	$\overline{RD}$ Pulse Width	250		ns	
t_{AD}	Data Delay from Address		300	ns	Note 2
t_{RD}	Data Delay from $\overline{RD}$		200	ns	C_L = 150 pF, Note 2
t_{DF}	Output Float Delay	20	100	ns	C_L = 20 pF for Minimum; 150 pF for Maximum
t_{DC}	DACK Setup to $\overline{RD}$	25		ns	
t_{CD}	DACK Hold from $\overline{RD}$	25		ns	
t_{KD}	Data Delay from DACK		300	ns	

WRITE CYCLE

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AC}	Select Setup to $\overline{WR}$	0		ns	
t_{CA}	Select Hold from $\overline{WR}$	0		ns	
t_{WW}	$\overline{WR}$ Pulse Width	250		ns	
t_{DW}	Data Setup to $\overline{WR}$	150		ns	
t_{WD}	Data Hold from $\overline{WR}$	0		ns	
t_{DC}	DACK Setup to $\overline{WR}$	25		ns	
t_{CD}	DACK Hold from $\overline{WR}$	25		ns	

DMA

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{CQ}	Request Hold from $\overline{WR}$ or $\overline{RD}$ (for Non-Burst Mode)		200	ns	

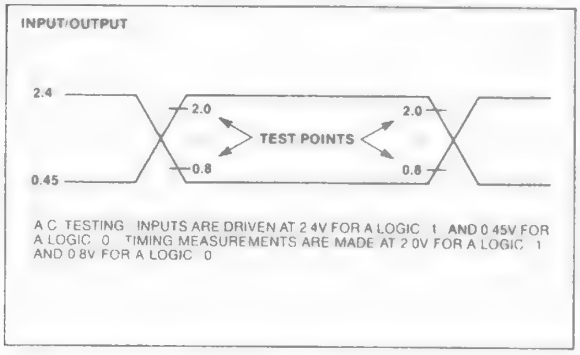
OTHER TIMING

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{RSTW}	Reset Pulse Width	10		t_{CY}	
t_r	Input Signal Rise Time		20	ns	
t_f	Input Signal Fall Time		20	ns	
t_{RSTS}	Reset to First $\overline{IOWR}$	2		t_{CY}	
t_{CY32}	32X Clock Cycle Time	$13.02 \cdot t_{CY}$		ns	
t_{CL32}	32X Clock Low Time	$4 \cdot t_{CY}$		ns	
t_{CH32}	32X Clock High Time	$4 \cdot t_{CY}$		ns	
t_{DPLL}	$\overline{DPLL}$ Output Low	$1 \cdot t_{CY} - 50$		ns	
t_{DCL}	Data Clock Low	$1 \cdot t_{CY} - 50$		ns	
t_{DCH}	Data Clock High	$2 \cdot t_{CY}$		ns	
t_{DCY}	Data Clock	$62.5 \cdot t_{CY}$		ns	Note 3
t_{TD}	Transmit Data Delay		200	ns	
t_{DS}	Data Setup Time	200		ns	
t_{DH}	Data Hold Time	100		ns	
t_{FLD}	$\overline{FLAG\ DET}$ Output Low	$8 \cdot t_{CY} \pm 50$		ns	

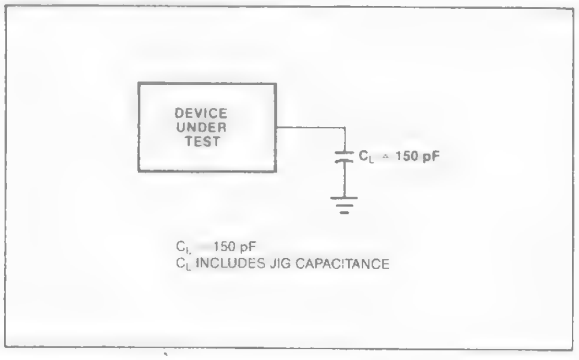
NOTES:

1. All timing measurements are made at the reference voltages unless otherwise specified: Input "1" at 2.0V, "0" at 0.8V; Output "1" at 2.0V, "0" at 0.8V.
2. t_{AD}, t_{RD}, t_{AC}, and t_{CA} are not concurrent specs.
3. If receive commands or Read/Write Port commands are issued while both the transmitter and receiver are active, this specification will be 81.5 T_{CY} min.

A.C. TESTING INPUT, OUTPUT WAVEFORM

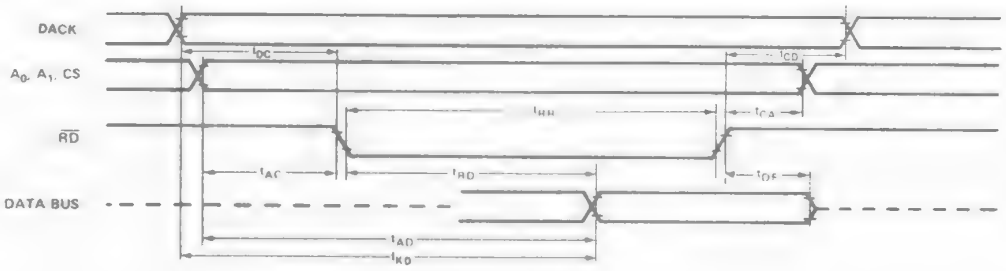


A.C. TESTING LOAD CIRCUIT

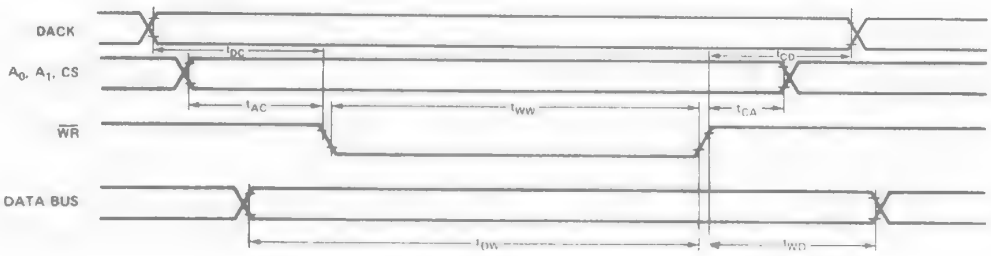


WAVEFORMS

READ

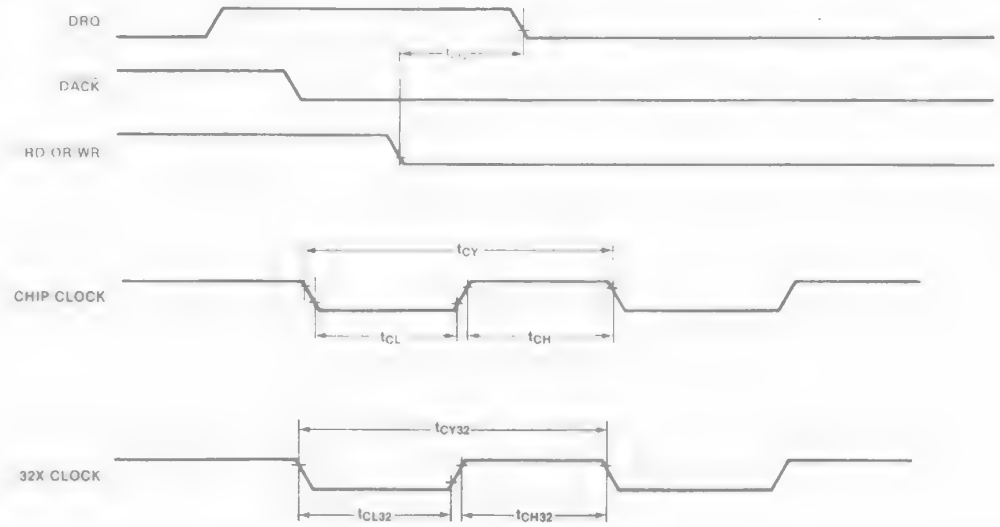


WRITE

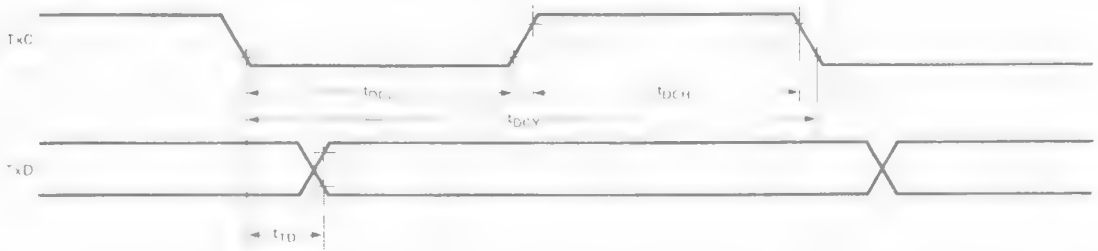


WAVEFORMS (Continued)

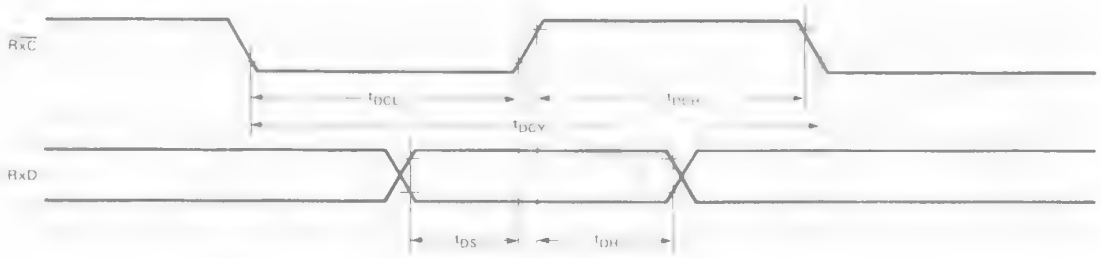
DMA



TRANSMIT



RECEIVE



AFN-00743C

WAVEFORMS (Continued)

DPLL OUTPUT

FLAG DETECT OUTPUT

PRELIMINARY

8274
MULTI-PROTOCOL SERIAL CONTROLLER (MPSC)

- **Asynchronous, Byte Synchronous and Bit Synchronous Operation**
- **Two Independent Full Duplex Transmitters and Receivers**
- **Fully Compatible with 8048, 8051, 8085, 8088, and 8086 CPU's; 8257 and 8237 DMA Controllers; and 8089 I/O Proc.**
- **4 Independent DMA Channels**
- **Baud Rate: DC to 880K Baud**
  —Future Selections to 1M Baud
- **Asynchronous:**
  —5-8 Bit Character; Odd, Even, or No Parity; 1, 1.5 or 2 Stop Bits
  —Error Detection: Framing, Overrun, and Parity
- **Byte Synchronous:**
  – Character Synchronization, Int. or Ext.
  – One or Two Sync Characters
  – Automatic CRC Generation and Checking (CRC-16)
  – IBM Bisync Compatible
- **Bit Synchronous:**
  – SDLC/HDLC Flag Generation and Recognition
  – 8 Bit Address Recognition
  – Automatic Zero Bit Insertion and Deletion
  – Automatic CRC Generation and Checking (CCITT-16)
  – CCITT X.25 Compatible
- **Available in EXPRESS**
  —Standard Temperature Range

The Intel® 8274 Multi-Protocol Series Controller (MPSC) is designed to interface High Speed Communications Lines using Asynchronous, IBM Bisync, and SDLC/HDLC protocol to Intel microcomputer systems. It can be interfaced with Intel's MCS-48, -85, -51; iAPX-86, and -88 families, the 8237 DMA Controller, or the 8089 I/O Processor in polled, interrupt driven, or DMA driven modes of operation.

The MPSC is a 40 pin device fabricated using Intel's High Performance HMOS Technology.

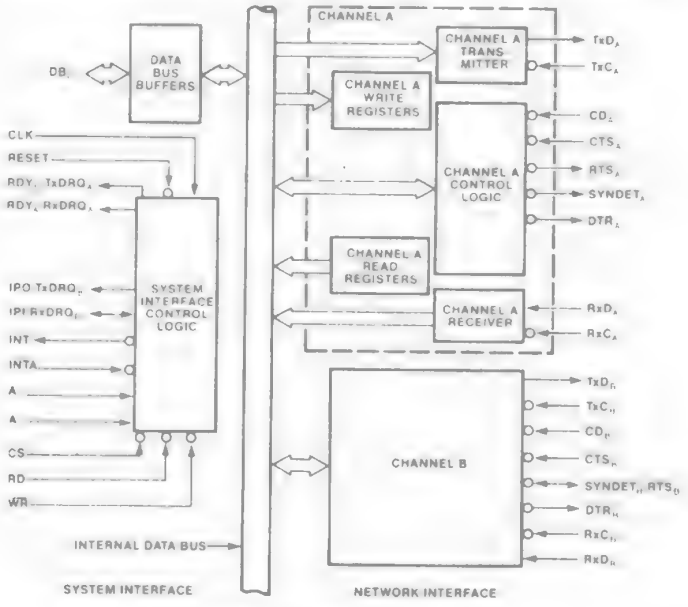


Figure 1. Block Diagram

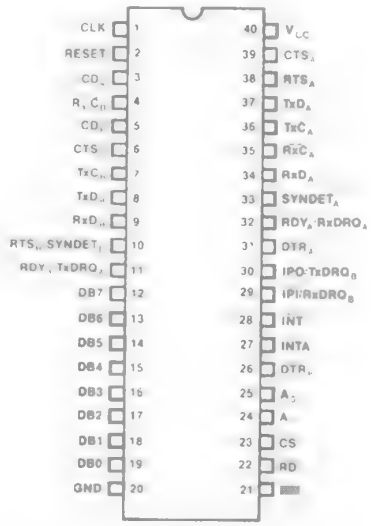


Figure 2. Pin Configuration

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DECEMBER 1981

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
CLK	1	I	**Clock:** System clock, TTL compatible.
$\overline{RESET}$	2	I	**Reset:** A low signal on this pin will force the MPSC to an idle state. TxD_A and TxD_B are forced high. The modem interface output signals are forced high. The MPSC will remain idle until the control registers are initialized. Reset must be true for one complete CLK cycle.
$\overline{CD_A}$	3	I	**Carrier Detect (Channel A):** Carrier Detect (Channel A) signals that the line transmission has started. The MPSC will begin to sample data on the RxD_A line if modem enables are selected.
$\overline{RxC_B}$	4	I	**Receiver Clock:** The Receiver Clock (Channel B) clocks in data on the RxD_B pin.
$\overline{CD_B}$	5	I	**Carrier Detect (Channel B):** Carrier Detect (Channel B) signals that the line transmission has started. The MPSC will begin to sample data on the RxD_B line if modem enables are selected.
$\overline{CTS_B}$	6	I	**Clear To Send (Channel B):** Clear To Send (Channel B) signals that the modem is ready to accept data from the MPSC. Clear To Send will enable Channel B transmitter if modem enables are selected, otherwise this pin may be used as a general purpose input.
$\overline{TxC_B}$	7	I	**Transmit Clock (Channel B):** Transmit Clock (Channel B) for TxD_B pin.
TxD_B	8	O	**Transmit Data (Channel B):** This line transmits the serial data to the communications channel (Channel B).
RxD_B	9	I	**Receive Data (Channel B):** This line receives serial data from the communications channel (Channel B).
$\overline{SYNDET_B}$/ $\overline{RTS_B}$	10	I/O	**Synchronous Detection (Channel B):** This pin is used in byte synchronous mode as either an internal sync detect (output) or as a means to force external synchronization (input). In SDLC mode, this pin is an output indicating Flag detection. In asynchronous mode it is a general purpose input (Channel B). Request To Send (Channel B) is a general purpose output, generally used to signal that Channel B is ready to send data.
RDY_B/ $TxDRQ_A$	11	O	**Ready Transmit Data:** In mode 0 this pin is used to synchronize data transfers for both Receive and Transmit of Channel B to the controlling processor's READY line (open collector). In modes 1 and 2 this pin requests a DMA transfer of data for a transmit operation (Channel A).
DB7	12	I/O	**Data Bus:** The Data Bus lines are bi-directional three state lines which interface with the system's Data Bus.
DB6	13		
DB5	14		
DB4	15		
DB3	16		
DB2	17		
DB1	18		
DB0	19		
GND	20		**Ground.**
V_{CC}	40		**Power:** +5V Supply.
$\overline{CTS_A}$	39	I	**Clear To Send (Channel A):** This signals that the modem is ready to accept data from the MPSC. Clear To Send will enable Channel B transmitter if modem enables are selected, otherwise this pin may be used as a general purpose input.
$\overline{RTS_A}$	38	O	**Request To Send (Channel A):** Request To Send (Channel A) is a general purpose output generally used to signal that Channel A is ready to send data.
TxD_A	37	O	**Transmit Data (Channel A):** This line transmits the serial data to the communications channel (Channel A).
$\overline{TxC_A}$	36	I	**Transmitter Clock (Channel A):** The transmitter clock (Channel A) clocks out data on the TxD_A pin.
$\overline{RxC_A}$	35	I	**Receiver Clock (Channel A):** The receiver clock (Channel A) clocks in data on the RxD_A pin.
RxD_A	34	I	**Receive Data (Channel A):** This line receives serial data from the communications channel (Channel A).
$\overline{SYNDET_A}$	33	I/O	**Synchronous Detection (Channel A):** This pin is used in byte synchronous mode as either an internal sync detect (output) or as a means to force external synchronization (input). In SDLC mode, this pin is an output indicating flag detection. In asynchronous mode it is a general purpose input (Channel A).

Table 1. Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{RDY_A}$, $RxDRQ_A$	32	O	**Ready:** In mode 0 this pin is used to synchronize data transfers for both receive and transmit of Channel A to the controlling processor's READY line (open collector). In modes 1 and 2 $RxDRQ_A$ requests a DMA transfer of data for a receive operation for Channel A.
DTR_A	31	O	**Data Terminal Ready:** This pin is Data Terminal Ready (Channel A) which is a general purpose output.
$\overline{IPO}$/ $TxDRQ_B$	30	O	**Interrupt Priority Out:** In modes 0 and 1, IPO is Interrupt Priority Out. It is used to establish a hardware interrupt priority scheme with IPI. It is low only if IPI is low and the controlling processor is not servicing an interrupt from this MPSC. In mode 2, $TxDRQ_B$ requests a DMA transfer of data for a transmit operation for Channel B.
$\overline{IPI}$ $RxDRQ_B$	29	I/O	**Interrupt Priority In:** In modes 0 and 1, IPI is Interrupt Priority In. A low on IPI means that no higher priority device is being serviced by the controlling processor's interrupt service routine. In mode 2, $RxDRQ_B$ requests a DMA transfer of data for a receive operation for Channel B. In Interrupt mode, this pin must be tied low.

Symbol	Pin No.	Type	Name and Function
$\overline{INT}$	[illegible]	O	**Interrupt:** The interrupt signal indicates that the highest priority internal interrupt requires service (open collector). Priority can be resolved via an external interrupt controller or a daisy-chain scheme.
$\overline{INTA}$	27	I	**Interrupt Acknowledge:** This Interrupt Acknowledge allows the highest priority interrupting device to generate an interrupt vector. This pin must be pulled high (inactive) in non-vector mode.
$\overline{DTR_B}$	[illegible]	O	**Data Terminal Ready (Channel B):** This is a general purpose output.
A_0	25	I	**Address:** This line selects Channel A or B during data or command transfers. A low selects Channel A.
A_1	24	I	**Address:** This line selects between data or command information transfer. A low means data.
$\overline{CS}$	23	I	**Chip Select:** Chip Select enables RD or WR.
$\overline{RD}$	22	I	**Read:** Read controls a data byte or status byte transfer from the MPSC to CPU.
$\overline{WR}$	21	I	**Write:** Write controls transfer of data or commands to the MPSC.

GENERAL DESCRIPTION

The Intel® 8274 Multi-Protocol Serial Controller is a microcomputer peripheral device which supports Asynchronous (Start/Stop), Byte Synchronous (Monosync, IBM Bisync), and Bit Synchronous (ISO's HDLC, IBM's SDLC) protocols. This controller's flexible architecture allows easy implementation of many variations of these three protocols with low software and hardware overhead.

The Multi-Protocol Serial Controller (MPSC) implements two independent serial receiver/transmitter channels.

The MPSC supports several microprocessor interface options; Polled, Wait, Interrupt driven and DMA driven. The MPSC is designed to support Intel's® MCS-85 and iAPX 86, 88 families.

This data sheet will describe the serial protocol functions, the microprocessor interface, a detailed register and command description, general system operations, specifications, and waveforms.

FUNCTIONAL DESCRIPTION

This section of the data sheet describes how the Asynchronous and Synchronous protocols are implemented in the MPSC. It describes general considerations, transmit operation, and receive operation for Asynchronous, Byte Synchronous, and Bit Synchronous protocols.

ASYNCHRONOUS OPERATIONS

General

For operation in the asynchronous mode, the MPSC must be initialized with the following information: character length (WR3; D7, D6 and WR5; D6, D5), clock rate (WR4; D7, D6), number of stop bits (WR4; D3, D2), odd, even or no parity (WR4; D1, D0), interrupt mode (WR1, WR2), and receiver (WR3; D0) or transmitter (WR5; D3) enable. When loading these parameters into the MPSC, WR4 information must

be written before the WR1, WR3, WR5 parameters/commands. (See Detailed Command Description Section).

For transmission via a modem or RS232C interface, the Request To Send (RTS) (WR5; D1) and Data Terminal Ready (DTR) (WR5; D7) bits must be set along with the Transmit Enable bit (WR5; D3). Setting the Auto Enables (WR3; D5) bit allows the programmer to send the first character of the message without waiting for a clear to send (CTS).

Both the Framing Error and Receive Overrun Error flags are latched and cause an interrupt, i.e., if status affects vector (WR1B; D2) is selected, the interrupt vector indicates a special Receive condition.

If the External/Status Interrupt bit (WR1; D0) is enabled, Break Detect (RR0; D7) and Carrier Detect (RR0; D3) will cause an interrupt. Reset External/Status Interrupts (WR0; D5, D4, D3) will clear Break Detect and Carrier Detect bits if they are set.

A status read after a data read will include error status for the next word in the buffer. If the Interrupt on First Character (WR1; D4, D3) is selected, then data and error status are held until an Error Reset command (WR0; D5, D4, D3) is given.

If the Interrupt on Every Character Mode bit (WR1; D4, D3) is selected, the interrupt vector is different if there is an error status in RR1. When the character is read, the error status bit is set and the Special Receive Condition vector is returned if Status Affects vector (WR1B; D2) is selected.

In a polled environment, the Receive Character Available bit (RR0; D0) must be monitored so that the CPU can determine when data is available. The bit is reset automatically when the data is read.

If the X1 clock mode is selected, the bit synchronization must be accomplished externally.

Transmit

The transmit function begins when the Transmit Enable bit (WR5; D3) is set. The MPSC automatically adds the start bit, the programmed parity bit (odd, even or no parity) and the programmed number of stop bits (1, 1.5 or 2 bits) to the data character being transmitted. 1.5 stop bits option must be used with X16, X32 or X64 clock option only.

The Serial data is shifted out from the Transmit Data (TxD) output on the falling edge of the Transmit Clock (TxC) input, at a rate programmable to 1, 1/16, 1/32nd, or 1/64th of the clock rate supplied to the TxC input.

The TxD output is held high when the transmitter has no data to send, unless, under program control, the Send Break (WR5; D4) command is issued to hold the TxD low.

If the External/STATUS Interrupt bit (WR1; D0) is set, the status of CD, CTS and SYNDET are monitored, and, if any changes occur for a period of time greater than the minimum specified pulse width, an interrupt is generated. CTS is usually monitored using this interrupt feature.

If the Auto Enables (WR; D5) option is selected, the programmer must wait for the CTS before sending the first character. The MPSC will generate an External/STATUS Interrupt when CTS becomes active and at this point the first data character should be sent to the MPSC.

The Transmit Buffer Empty bit (RR0; D2) is set by the MPSC when the data byte from the buffer is loaded in the transmit shift register. The data is written to the MPSC only when the Tx buffer becomes empty to prevent overwriting.

Asynchronous Mode Register Setup

	D7	D6	D5	D4	D3	D2	D1	D0
WR3	00 Rx 5 b/char 01 Rx 7 b/char 10 Rx 6 b/char 11 Rx 8 b/char		AUTO ENABLES	0	0	0	0	Rx ENABLE
WR4	00 X1 Clock 01 X16 Clock 10 X32 Clock 11 X64 Clock		0	0	00 ENABLE SYNC MODES 01 1 STOP BIT 10 1½ STOP BITS 11 2 STOP BITS		EVEN/ ODD PARITY	PARITY ENABLE
WR5	DTR	00 Tx 5 b/char 01 Tx 7 b/char 10 Tx 6 b/char 11 Tx 8 b/char		SEND BREAK	Tx ENABLE	0	RTS	0

*Active, and at this point, the first data character should be sent to the MPSC.

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Receive

The receive function begins when the Receive Enable (WR3; D0) bit is set. If the Auto Enables (WR3; D5) option is selected, then Carrier Detect (CD) must also be low. A valid start bit is detected if a low persists for at least 1/2 bit time on the Receive Data (RxD) input.

The data is sampled at mid-bit time, on the rising edge of RxC, until the entire character is assembled. The receiver inserts 1's when a character is less than 8 bits. If parity (WR4; D1, D0) is enabled and the character is less than 8 bits the parity bit is not stripped from the character.

The receiver also stores error status for each of the 3 data characters in the data buffer. When a parity error is detected, the parity error flag (RR1; D4) is set and remains set until it is reset by the Error Reset command (WR0; D5, D4, D3).

When a character is assembled without a stop bit being detected, the Framing Error bit (RR1; D6) is set. The detection of a Framing Error adds an additional 1/2 bit time to the character time so the Framing Error is not interpreted as a new start bit.

If the CPU fails to read a data character while more than three characters have been received, the Receive Overrun bit (RR1; D5) is set. Only the overwritten character is flagged with the Receive Overrun bit. When this occurs, the fourth character assembled replaces the third character in the receive buffers. The Receive Overrun bit (RR1; D5) is reset by the Error Reset command (WR0; D5, D4, D3).

SYNCHRONOUS OPERATION—MONO SYNC, BI SYNC

General

The MPSC must be initialized with the following parameters: odd or even parity (WR4; D1,D0), X1 clock mode (WR4; D7, D6), 8- or 16-bit sync character (WR4; D5, D4), CRC polynomial (WR5; D2), Transmitter Enable (WR5; D3), interrupt modes (WR1, WR2), transmit character length (WR5; D6, D5) and receive character length (WR3; D7, D6). WR4 parameters must be written before WR1, WR3, WR5, WR6 and WR7.

The data is transmitted on the falling edge of the Transmit Clock, (TxC) and is received on the rising edge of Receive Clock (RxC). The X1 clock is used for both transmit and receive operations for all three sync modes: Mono, Bi and External.

Transmit Set-Up—Monosync, Bisync

Transmit data is held high after channel reset, or if the transmitter is not enabled. A break may be programmed to generate a spacing line that begins as soon as the Send Break (WR5; D4) bit is set. With the transmitter fully initialized and enabled, the default condition is continuous transmission of the 8- or 16-bit sync character.

Using interrupts for data transfer requires that the Transmit Interupt/DMA Enable bit (WR1; D1) be set. An interrupt is generated each time the transmit buffer becomes empty. The interrupt can be satisfied

Synchronous Mode Register Setup—Monosync, Bisync

	D7	D6	D5	D4	D3	D2	D1	D0
WR3	00 Rx 5 b/char 01 Rx 7 b/char 10 Rx 6 b/char 11 Rx 8 b/char		AUTO ENABLES	ENTER HUNT MODE	Rx CRC ENABLE	0	SYNC CHAR LOAD INHIBIT	Rx ENABLE
WR4	0	0	00 8 bit Sync 01 16 bit Sync 11 Ext Sync		0	0	EVEN/ $\overline{\text{ODD}}$ PARITY	PARITY ENABLE
WR5	DTR	00 Tx 5 b/char 01 Tx 7 b/char 10 Tx 6 b/char 11 Tx 8 b/char		SEND BREAK	Tx ENABLE	1 (SELECTS CRC-16)	RTS	Tx CRC ENABLE

either by writing another character into the transmitter or by resetting the Transmitter Interrupt/DMA Pending latch with a Reset Transmitter Interrupt/DMA Pending Command (WR0; D5, D4, D3). If nothing more is written into the transmitter, there can be no further Transmit Buffer Empty interrupt, but this situation does cause a Transmit Underrun condition (RR0; D6).

Data Transfers using the RDY signal are for software controlled data transfers such as block moves. $\overline{\text{RDY}}$ tells the CPU that the MPSC is not ready to accept/provide data and that the CPU must extend the output/input cycle. DMA data transfers use the TxDRQ A/B signals which indicate that the transmit buffer is empty, and that the MPSC is ready to accept the next data character. If the data character is not loaded into the MPSC by the time the transmit shift register is empty, the MPSC enters the Transmit Underrun condition.

The MPSC has two programmable options for solving the transmit underrun condition: it can insert sync characters, or it can send the CRC characters generated so far, followed by sync characters. Following a chip or channel reset, the Transmit Underrun/EOM status bit (RR0; D6) is in a set condition allowing the insertion of sync characters when there is no data to send. The CRC is not calculated on these automatically inserted sync characters. When the CPU detects the end of message, a Reset Transmit Underrun/EOM command can be issued. This allows CRC to be sent when the transmitter has no data to send.

In the case of sync insertion, an interrupt is generated only after the first automatically inserted sync character has been loaded in Transmit Shift Register. The status indicates the Transmit Underrun/EOM bit and the Transmit Buffer Empty bit are set.

In the case of CRC insertion, the Transmit Underrun/EOM bit is set and the Transmit Buffer Empty bit is reset while CRC is being sent. When CRC has been completely sent, the Transmit Buffer Empty status bit is set and an interrupt is generated to indicate to the CPU that another message can begin (this interrupt occurs because CRC has been sent and sync has been loaded into the Tx Shift Register). If no more messages are to be sent, the program can terminate transmission by resetting RTS, and disabiling the transmitter (WR5; D3).

Bisync CRC Generation. Setting the Transmit CRC enable bit (WR5; D0) indicates CRC accumulation when the program sends the first data character to the MPSC. Although the MPSC automatically transmits up to two sync characters (16 bit sync), it is wise to send a few more sync characters ahead of the message (before enabling Transmit CRC) to ensure synchronization at the receiving end.

The Transmit CRC Enable bit can be changed on the fly any time in the message to include or exclude a particular data character from CRC accumulation. The Transmit CRC Enable bit should be in the desired state when the data character is loaded from the transmit shift register. To ensure this bit in the proper state, the Transmit CRC Enable bit must be issued before sending the data character to the MPSC.

Transmit Transparent Mode. Transparent mode (Bisync protocol) operation is made possible by the ability to change Transmit CRC Enable on the fly and by the additional capability of inserting 16 bit sync characters. Exclusion of DLE characters from CRC calculation can be achieved by disabling CRC calculation immediately preceding the DLE character transfer to the MPSC.

In the transmit mode, the transmitter always sends the programmed number of sync bits (8 or 16) (WR4; D5, D4). When in the Monosync mode, the transmitter sends from WR6 and the receiver compares against WR7. One of two CRC polynomials, CRC 16 or SDLC, may be used with synchronous modes. In the transmit initialization process, the CRC generator is initialized by setting the Reset Transmit CRC Generator command (WR0; D7, D6).

The External/Status interrupt (WR1; D0) mode can be used to monitor the status of the CTS input as well as the Transmit Underrun/EOM latch. Optionally, the Auto Enable (WR3; D5) feature can be used to enable the transmitter when CTS is active. The first data transfer to the MPSC can begin when the External/Status interrupt occurs (CTS (RR0; D5) status bit set) following the Transmit Enable command (WR5; D3).

Receive

After a channel reset, the receiver is in the Hunt phase, during which the MPSC looks for character synchronization. The Hunt begins only when the receiver is enabled and data transfer begins only when character synchronization has been achieved. If character synchronization is lost, the hunt phase can be re-entered by writing the Enter Hunt Phase (WR3; D4) bit. The assembly of received data continues until the MPSC is reset or until the receiver is

disabled (by command or by $\overline{CD}$ while in the Auto Enables mode) or until the CPU sets the Enter Hunt Phase bit. Under program control, all the leading sync characters of the message can be inhibited from loading the receive buffers by setting the Sync Character Load Inhibit (WR3; D1) bit. After character synchronization is achieved the assembled characters are transferred to the receive data FIFO. After receiving the first data character, the Sync Character Load Inhibit bit should be reset to zero so that all characters are received, including the sync characters. This is important because the received CRC may look like a sync character and not get received.

Data may be transferred with or without interrupts. Transferring data without interrupts is used for a purely polled operation or for off-line conditions. There are three interrupt modes available for data transfer: Interrupt on First Character Only, Interrupt on Every Character, and Special Receive Conditions Interrupt.

Interrupt on First Character Only mode is normally used to start a polling loop, a block transfer sequence using RDY to synchronize the CPU to the incoming data rate or a DMA transfer using the RxDRQ signal. The MPSC interrupts on the first character and thereafter only interrupts after a Special Receive Condition is detected. This mode can be reinitialized using the Enable Interrupt On Next Receive Character (WR0; D5, D4, D3) command which allows the next character received to generate an interrupt. Parity Errors do not cause interrupts, but End of Frame (SDLC operation) and Receive Overrun do cause interrupts in this mode. If the external status interrupts (WR1; D0) are enabled an interrupt may be generated any time the $\overline{CD}$ changes state.

Interrupt On Every Character mode generates an interrupt whenever a character enters the receive buffer. Errors and Special Receive Conditions generate a special vector if the Status Affects Vector (WR1B; D2) is selected. Also the Parity Error may be programmed (WR1; D4, D3) not to generate the special vector while in the Interrupt On Every Character mode.

The Special Receive Condition interrupt can only occur while in the Receive Interrupt On First Character Only or the Interrupt On Every Receive Character modes. The Special Receive Condition interrupt is caused by the Receive Overrun (RR1; D5) error condition. The error status reflects an error in the current word in the receive buffer, in addition to any Parity or Overrun errors since the last Error Reset (WR0; D5, D4, D3). The Receive Overrun and Parity error status bits are latched and can only be reset by the Error Reset (WR0; D5, D4, D3) command.

The CRC check result may be obtained by checking for CRC bit (RR1; D6). This bit gives the valid CRC result 16 bit times after the second CRC byte has been read from the MPSC. After reading the second CRC byte, the user software must read two more characters (may be sync characters) before checking for CRC result in RR1. Also for proper CRC computation by the receiver, the user software must reset the Receive CRC Checker (WR0; D7, D6) after receiving the first valid data character. The receive CRC Enable bit (WR3; D3) may also be enabled at this time.

SYNCHRONOUS OPERATION—SDLC

General

Like the other synchronous operations the SDLC mode must be initialized with the following parameters: SDLC mode (WR4; D5, D4), SDLC polynomial (WR5; D2), Request to Send, Data Terminal Ready,

Synchronous Mode Register Setup—SDLC/HDLC

	D7	D6	D5	D4	D3	D2	D1	D0
WR3	00 Rx 5b/char 01 Rx 7b/char 10 Rx 6b/char 11 Rx 8b/char		AUTO ENABLES	ENTER HUNT MODE	Rx CRC ENABLE	ADDRESS SEARCH MODE	0	Rx ENABLE
WR4	0	0	1	0 (SELECTS SDLC/ HDLC MODE)	0	0	0	0
WR5	DTR	00 Tx ≤5b/char 01 Tx 7b/char 10 Tx 6b/char 11 Tx 8b/char		0	Tx ENABLE	0 (SELECTS SDLC/ HDLC CRC)	RTS	Tx CRC ENABLE

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transmit character length (WR5; D6, D5), interrupt modes (WR1; WR2), Transmit Enable (WR5; D3), Receive Enable (WR3; D0), Auto Enable (WR3; D5) and External/Status Interrupt (WR1; D0).WR4 parameters must be written before WR1, WR3, WR5, WR6 and WR7.

The Interrupt modes for SDLC operation are similar to those discussed previously in the synchronous operations section.

Transmit

After a channel reset, the MPSC begins sending SDLC flags.

Following the flags in an SDLC operation the 8-bit address field, control field and information field may be sent to the MPSC by the microprocessor. The MPSC transmits the Frame Check Sequence using the Transmit Underrun feature. The MPSC automatically inserts a zero after every sequence of 5 consecutive 1's except when transmitting Flags or Aborts.

SDLC—like protocols do not have provision for fill characters within a message. The MPSC therefore automatically terminates an SDLC frame when the transmit data buffer and output shift register have no more bits to send. It does this by sending the two bytes of CRC and then one or more flags. This allows very high-speed transmissions under DMA or CPU control without requiring the CPU to respond quickly to the end-of-message situation.

After a reset, the Transmit Underrun/EOM status bit is in the set state and prevents the insertion of CRC characters during the time there is no data to send. Flag characters are sent. The MPSC begins to send the frame when data is written into the transmit buffer. Between the time the first data byte is written, and the end of the message, the Reset Transmit Underrun/EOM (WR0; D7, D6) command must be issued. The Transmit Underrun/EOM status bit (RR0; D6) is in the reset state at the end of the message which automatically sends the CRC characters.

The MPSC may be programmed to issue a send Abort command (WR0; D5, D4, D3). This command causes at least eight 1's but less than fourteen 1's to be sent before the line reverts to continuous flags.

Receive

After initialization, the MPSC enters the Hunt phase, and remains in the Hunt phase until the first Flag is received. The MPSC never again enters the Hunt phase unless the microprocessor writes the Enter Hunt command. The MPSC will also detect flags separated by a single zero. For example, the bit pattern 011111101111110 will be detected as two flags.

The MPSC can be programmed to receive all frames or it can be programmed to the Address Search Mode. In the Address Search Mode, only frames with addresses that match the value in WR6 or the global address (0FFH) are received by the MPSC. Extended address recognition must be done by the microprocessor software.

The control and information fields are received as data.

SDLC/HDLC CRC calculation does not have an 8-bit delay, since all characters are included in the calculation, unlike Byte Synchronous Protocols.

Reception of an abort sequence (7 or more 1's) will cause the Break/Abort bit (RR0; D7) to be set and will cause an External/Status interrupt, if enabled. After the Reset External/Status Interrupts Command has been issued, a second interrupt will occur at the end of the abort sequence.

MPSC

Detailed Command Description

GENERAL

The MPSC supports an extremely flexible set of serial and system interface modes.

The system interface to the CPU consists of 8 ports or buffers:

$\overline{CE}$	A_1	A_0	Read Operation	Write Operation
0	0	0	Ch A Data Read	Ch A Data Write
0	1	0	Ch A Status Read	Ch A Command/Parameter
0	0	1	Ch B Data Read	Ch B Data Write
0	1	1	Ch B Status Read	Ch B Command/Parameter
1	X	X	High Impedence	High Impedence

Data buffers are addressed by $A_1 = 0$, and Command ports are addressed by $A_1 = 1$.

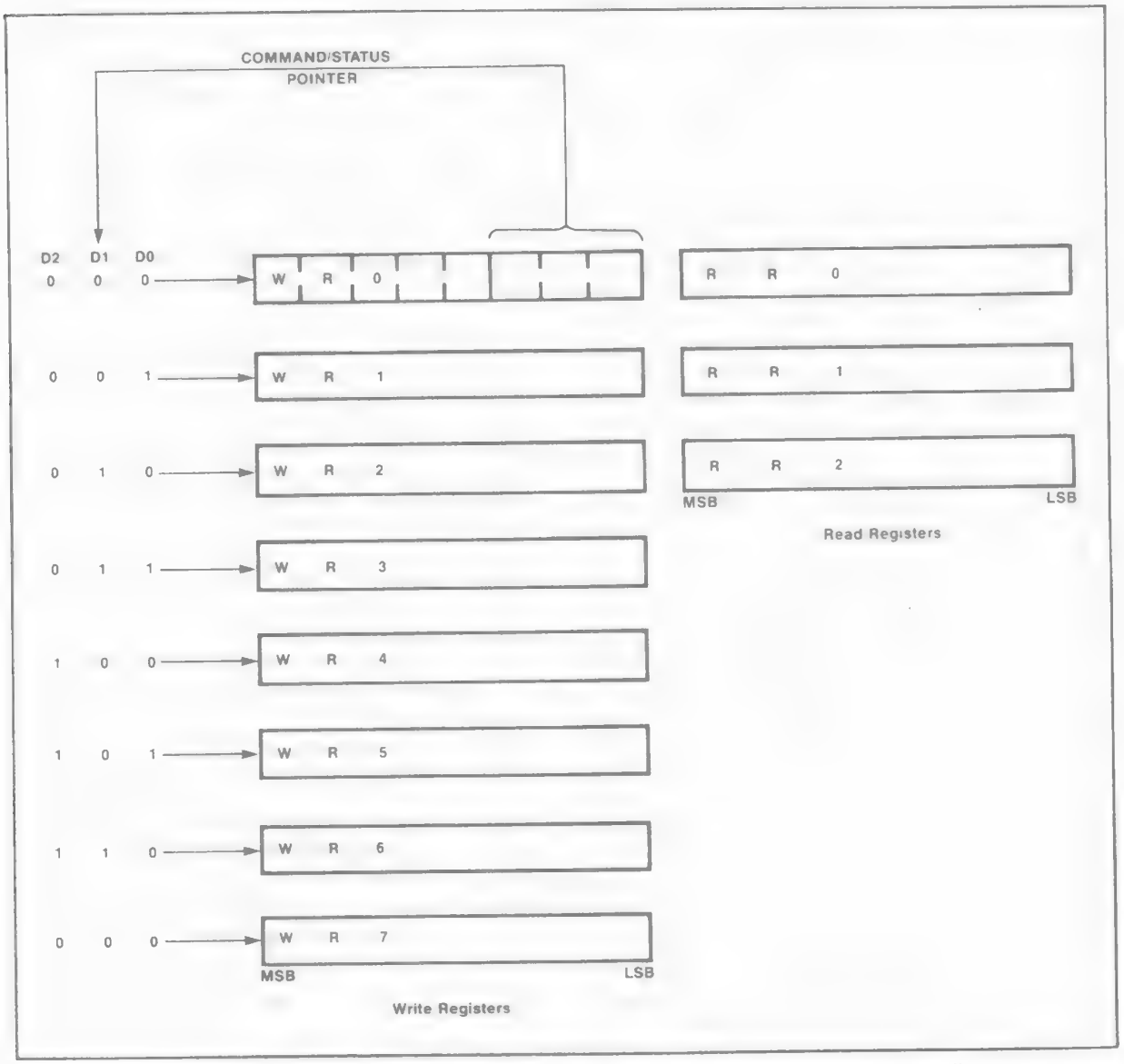


Figure 3. Command/Status Register Architecture (each serial channel)

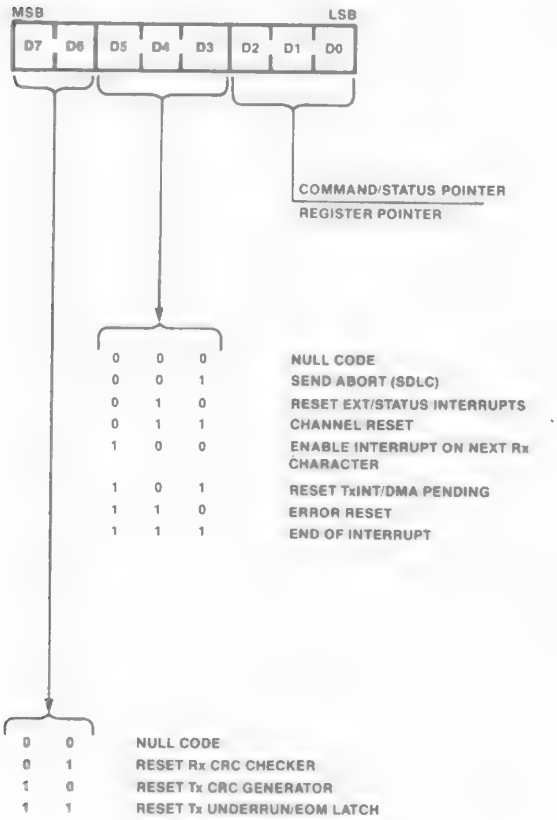
Command, parameter, and status information is held in 22 registers within the MPSC (8 write registers and 3 read registers for each channel). They are all accessed via the command ports.

An internal pointer register selects which of the command or status registers will be read or written during a command/status access of an MPSC channel.

After reset, the contents of the pointer register are zero. The first write to a command register causes the data to be loaded into Write Register 0 (WR0). The three least significant bits of WR0 are loaded into the Command/Status Pointer. The next read or write operation accesses the read or write register selected by the pointer. The pointer is reset after the read or write operation is completed.

COMMAND/STATUS DESCRIPTION
The following command and status bytes are used during initialization and execution phases of operation. All Command/Status operations on the two channels are identical, and independent, except where noted.

Write Register 0 (WR0):



Detailed Register Description

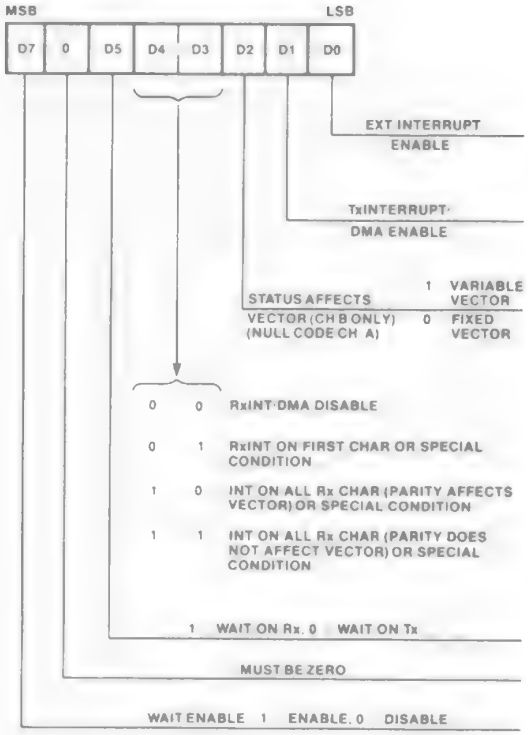
WR0
D2, D1, D0—Command/Status Register Pointer bits determine which write-register the next byte is to be written into, or which read-register the next byte is to be read from. After reset, the first byte written into either channel goes into WR0. Following a read or write to any register (except WR0) the pointer will point to WR0.

D5, D4, D3—Command bits determine which of the basic seven commands are to be performed.

Command 0	Null—has no effect.
Command 1	Send Abort—causes the generation of eight to thirteen 1's when in the SDLC mode.
Command 2	Reset External/Status Interrupts—resets the latched status bits of RR0 and re-enables them, allowing interrupts to occur again.
Command 3	Channel Reset—resets the Latched Status bits of RR0, the interrupt prioritization logic and all control registers for the channel. Four extra system clock cycles should be allowed for MPSC reset time before any additional commands or controls are written into the channel.
Command 4	Enable Interrupt on Next Receive Character—if the Interrupt on First Receive Character mode is selected, this command reactivates that mode after each complete message is received to prepare the MPSC for the next message.
Command 5	Reset Transmitter Interrupt/DMA Pending—if The Transmit Interrupt/DMA Enable mode is selected, the MPSC automatically interrupts or requests DMA data transfer when the transmit buffer becomes empty. When there are no more characters to be sent, issuing this command prevents further transmitter interrupts or DMA requests until the next character has been completely sent.
Command 6	Error Reset—error latches, Parity and Overrun errors in RR1 are reset.
Command 7	End of Interrupt—resets the interrupt-in-service latch of the highest-priority internal device under service.
D7, D6	CRC Reset Code
00	Null—has no effect.
01	Reset Receive CRC Checker—resets the CRC checker to 0's. If in SDLC mode the CRC checker is initialized to all 1's.

10	Reset Transmit CRC Generator—resets the CRC generator to 0's. If in SDLC mode the CRC generator's initialized to all 1's.
11	Reset Tx Underrun/End of Message Latch.

Write Register 1 (WR1):



D0	External/Status Interrupt Enable—allows interrupt to occur as the result of transitions on the $\overline{CD}$, $\overline{CTS}$ or $\overline{SYNDET}$ inputs. Also allows interrupts as the result of a Break/Abort detection and termination, or at the beginning of CRC, or sync character transmission when the Transmit Underrun/EOM latch becomes set.
D1	Transmitter Interrupt/DMA Enable—allows the MPSC to interrupt or request a DMA transfer when the transmitter buffer becomes empty.
D2	Status Affects vector—(WR1, D2 active in channel B only.) If this bit is not set, then the fixed vector, programmed in WR2, is returned from an interrupt acknowledge sequence. If the bit is set then the vector returned from an interrupt acknowledge is variable as shown in the Interrupt Vector Table.
D4, D3	Receive Interrupt Mode
0 0	Receive Interrupts/DMA Disabled
0 1	Receive Interrupt on First Character Only or Special Condition
1 0	Interrupt on All Receive Characters or Special Condition (Parity Error is a Special Receive Condition)
1 1	Interrupt on All Receive Characters or Special Condition (Parity Error is not a Special Receive Condition).
D5	Wait on Receive/$\overline{\text{Transmit}}$—when the following conditions are met the RDY pin is activated, otherwise it is held in the High-Z state. (Conditions: Interrupt Enabled Mode, Wait Enabled, $\overline{CS}$ = 0, A0 = 0/1, and A1 = 0). The RDY pin is pulled low when the transmitter buffer is full or the receiver buffer is empty and it is driven High when the transmitter buffer is empty or the receiver buffer is full. The RDY_A and RDY_B may be wired OR connected since only one signal is active at any one time while the other is in the High Z state.
D6	Must be Zero
D7	Wait Enable—enables the wait function.

WR2 **Channel A**

D1, D0 System Configuration—These specify the data transfer from MPSC channels to the CPU, either interrupt or DMA based.

0 0 Channel A and Channel B both use interrupts

0 1 Channel A uses DMA. Channel B uses interrupt

1 0 Channel A and Channel B both use DMA

1 1 Illegal Code

D2 Priority—this bit specifies the relative priorities of the internal MPSC interrupt/DMA sources.

0 (Highest) RxA, TxA, RxB, TxB ExTA, ExTB (Lowest)

1 (Highest) RxA, RxB, TxA, TxB, ExTA, ExTB (Lowest)

D5, D4, D3 Interrupt Code—specifies the behavior of the MPSC when it receives an interrupt acknowledge sequence from the CPU. (See Interrupt Vector Mode Table).

0 X X Non-vectored interrupts—intended for use with external DMA CONTROLLER. The Data Bus remains in a high impedence state during INTA sequences.

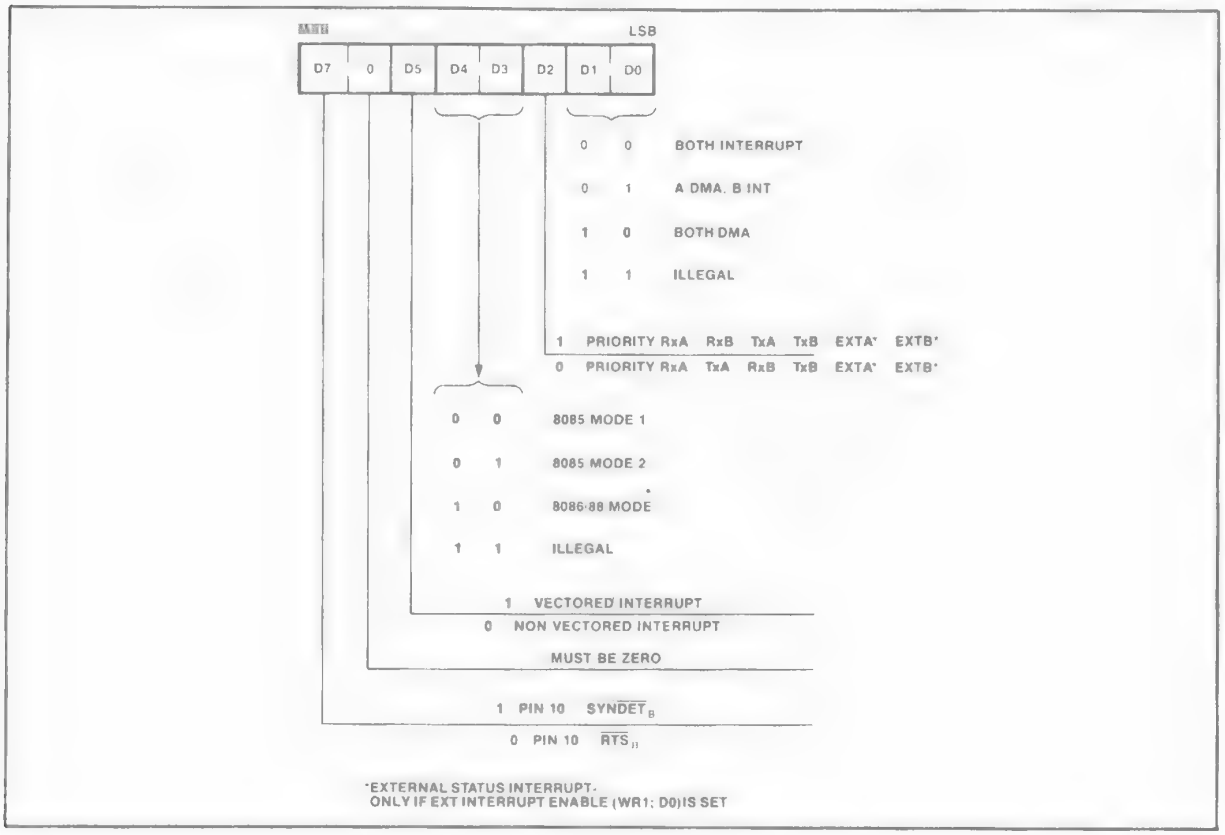
1 0 0 8085 Vector Mode 1—intended for use as the primary MPSC in a daisy chained priority structure. (See System Interface section)

1 0 1 8085 Vector Mode 2—intended for use as any secondary MPSC in a daisy chained priority structure. (See System Interface section)

1 1 0 8086/88 Vector Mode—intended for use as either a primary or secondary in a daisy chained priority structure. (See System Interface section)

D7, D6 Must be zero.

Write Register 2 (WR2): Channel A



The following table describes the MPSC's response to an interrupt acknowledge sequence:

D5	D4	D3	$\overline{IPI}$	MODE	INTA	Data Bus (D7 … D0)
0	X	X	X	Non-vectored	Any INTA	High Impedance
1	0	0	0	85 Mode 1	1st INTA 2nd INTA 3rd INTA	1 1 0 0 1 1 0 1 V7 V6 V5 V4* V3* V2* V1 V0 0 0 0 0 0 0 0 0
1	0	0	1	85 Mode 1	1st INTA 2nd INTA 3rd INTA	1 1 0 0 1 1 0 1 High Impedance High Impedance
1	0	1	0	85 Mode 2	1st INTA 2nd INTA 3rd INTA	High Impedance High Impedance High Impedance
1	1	0	0	86 Mode	1st INTA 2nd INTA	High Impedance V7 V6 V5 V4 V3 V2* V1*V0*
1	1	0	1	86 Mode	1st INTA 2nd INTA	High Impedance High Impedance

These bits are variable if the "status affects vector" mode has been programmed, (WR1B, p.2).

Interrupt/DMA Mode, Pin Functions, and Priority

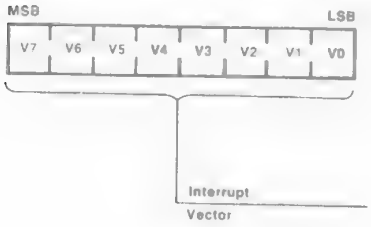
Ch. A WR2			Int/DMA Mode		Pin Functions				Priority
D_2	D_1	D_0	CH. A	CH. B	RDY_A/ $RxDRQ_A$ Pin 32	RDY_B/ $TxDRQ_A$ Pin 11	$\overline{IPI}$/ $RxDRQ_B$ Pin 29	$\overline{IPO}$/ $TxDRQ_B$ Pin 30	Highest … Lowest
0	0	0	INT	INT	RDY_A	RDY_B	$\overline{IPI}$	$\overline{IPO}$	RxA, TxA, RxB, TxB, EXT_A, EXT_B
1	0	0	INT	INT					RxA, RxB, TxA, TxB, EXT_A, EXT_B
0	0	1	DMA		$RxDRQ_A$	$TxDRQ_A$	$\overline{IPI}$	$\overline{IPO}$	RxA, TxA (DMA)
				INT					RxA[1], RxB, TxB, EXT_A, EXT_B (INT)
1	0	1	DMA						RxA, TxA (DMA)
				INT					RxA[1], RxB, TxB, EXT_A, EXT_B (INT)
0	1	0	DMA	DMA	$RxDRQ_A$	$TxDRQ_A$	$RxDRQ_B$	$TxDRQ_B$	RxA, TxA, RxB, TxB (DMA) RxA[1], RxB[1], EXT_A, EXT_B (INT)
1	1	0	DMA	DMA					RxA, RxB, TxA, TxB, (DMA) RxA[1], RxB[1], EXT_A, EXT_B (INT)

[1]Special Receive Condition

Interrupt Vector Mode Table

8085 Modes 8086/88 Mode	V_4 V_2	V_3 V_1	V_2 V_0	Channel	Condition
Note 1: Special Receive Condition – Parity Error, Rx Overrun Error, Framing Error, End of Frame (SDLC)	0	0	0	B	Tx Buffer Empty
	0	0	1		Ext/Status Change
	0	1	0		Rx Char. Available
	0	1	1		Special Rx Condition (Note 1)
	1	0	0	A	Tx Buffer Empty
	1	0	1		Ext/Status Change
	1	1	0		Rx Char. Available
	1	1	1		Special Rx Condition (Note 1)

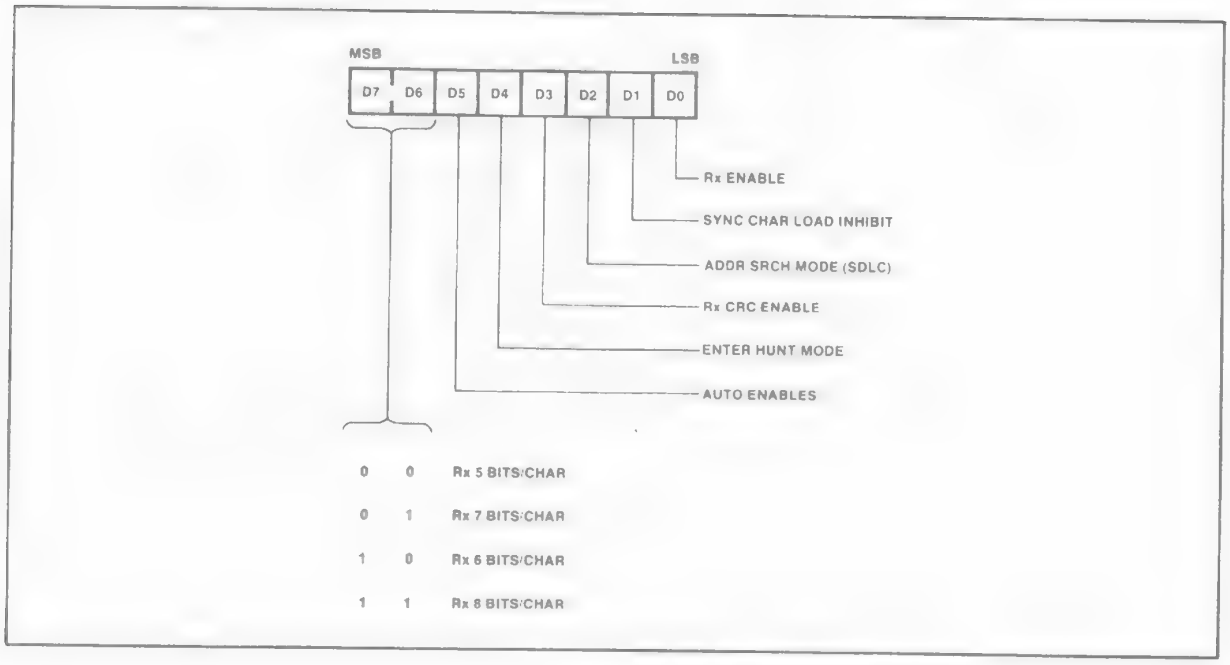
Write Register 2 (WR2): Channel B



WR2 CHANNEL B

D7–D0 Interrupt vector—This register contains the value of the interrupt vector placed on the data bus during interrupt acknowledge sequences.

Write Register 3 (WR3):



WR3

D0 Receiver Enable—A one enables the receiver to begin. This bit should be set only after the receiver has been initialized.

D1 Sync Character Load Inhibit—A one prevents the receiver from loading sync characters into the receive buffers. In SDLC, this bit must be zero.

D2 Address Search Mode—If the SDLC mode has been selected, the MPSC will receive all frames unless this bit is a 1. If this bit is a 1, the MPSC will receive only frames with address bytes that match the global address (0FFH) or the value loaded into WR6. This bit must be zero in non-SDLC modes.

D3 Receive CRC Enable—A one in this bit enables (or re-enables) CRC calculation. CRC calculation starts with the last character placed in the Receiver FIFO. A zero in this bit disables, but does not reset, the Receiver CRC generator.

D4 Enter Hunt Phase—After initialization, the MPSC automatically enters the Hunt mode. If synchronization is lost, the Hunt phase can be re-entered by writing a one to this bit.

D5 Auto Enables—A one written to this bit causes $\overline{CD}$ to be automatic enable signal for the receiver and $\overline{CTS}$ to be an automatic enable signal for the transmitter. A zero written to this bit limits the effect of $\overline{CD}$ and $\overline{CTS}$ signals to setting/resetting their corresponding bits in the status register (RR0).

D7, D6 Receive Character length

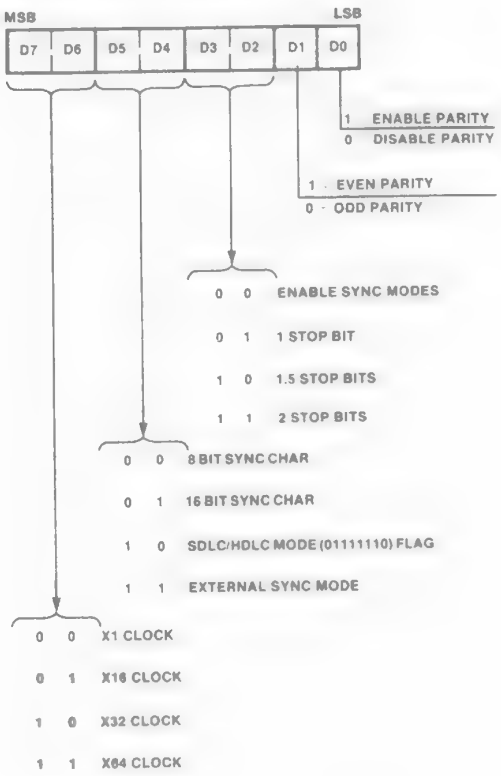
0 0 Receive 5 Data bits/character

0 1 Receive 7 Data bits/character

1 0 Receive 6 Data bits/character

1 1 Receive 8 Data bits/character

Write Register 4 (WR4):



WR4

D0 Parity—a one in this bit causes a parity bit to be added to the programmed number of data bits per character for both the transmitted and received character. If the MPSC is programmed to receive 8 bits per character, the parity bit is not transferred to the microprocessor. With other receiver character lengths, the parity bit is transferred to the microprocessor.

D1 Even/Odd Parity—if parity is enabled, a one in this bit causes the MPSC to transmit and expect even parity, and a zero causes it to send and expect odd parity.

D3, D2 Stop bits/sync mode

0 0	Selects synchronous modes.
0 1	Async mode, 1 stop bit/character
1 0	Async mode, 1-½ stop bits/character
1 1	Async mode, 2 stop bits/character

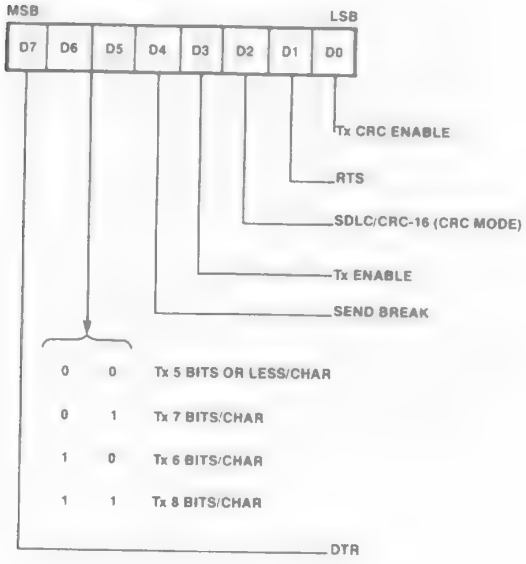
D5, D4 Sync mode select

0 0	8 bit sync character
0 1	16 bit sync character
1 0	SDLC mode (Flag sync)
1 1	External sync mode

D7, D6 Clock mode—selects the clock/data rate multiplier for both the receiver and the transmitter. 1x mode must be selected for synchronous modes. If the 1x mode is selected, bit synchronization must be done externally.

0 0	Clock rate = Data rate x 1
0 1	Clock rate = Data rate x 16
1 0	Clock rate = Data rate x 32
1 1	Clock rate = Data rate x 64

Write Register 5 (WR5):



WR5

D0 Transmit CRC Enable—a one in this bit enables the transmitter CRC generator. The CRC calculation is done when a character is moved from the transmit buffer into the shift register. A zero in this bit disables CRC calculations. If this bit is not set when a transmitter underrun occurs, the CRC will not be sent.

D1 Request to Send—a one in this bit forces the $\overline{RTS}$ pin active (low) and zero in this bit forces the $\overline{RTS}$ pin inactive (high).

D2 CRC Select—a one in this bit selects the CRC −16 polynomial ($X^{16} + X^{15} + X^2 + 1$) and a zero in this bit selects the CCITT-CRC polynomial ($X^{16} + X^{12} + X^5 + 1$). In SDLC mode, CCITT-CRC must be selected.

D3 Transmitter Enable—a zero in this bit forces a marking state on the transmitter output. If this bit is set to zero during data or sync character transmission, the marking state is entered after the character has been sent. If this bit is set to zero during transmission of a CRC character, sync or flag bits are substituted for the remainder of the CRC bits.

D4 Send Break—a one in this bit forces the transmit data low. A one in this bit allows normal transmitter operation.

D6, D5 Transmit Character length

0 0	Transmit 5 or less bits/character
0 1	Transmit 7 bits/character
1 0	Transmit 6 bits/character
1 1	Transmit 8 bits/character

Bits to be sent must be right justified least significant bit first, eg:

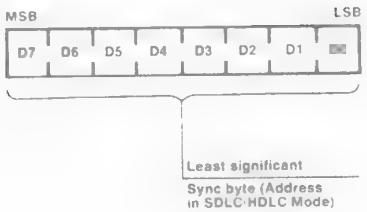
D7	D6	D5	D4	D3	D2	D1	D0
0	0	B5	B4	B3	B2	B1	B0

Five or less mode allows transmission of one to five bits per character. The microprocessor must format the data in the following way:

D7	D6	D5	D4	D3	D2	D1	D0	
1	1	1	1	1	1	1	B0	Sends one data bit
1	1	1	0	0	0	B1	B0	Sends two data bits
1	1	0	0	0	B2	B1	B0	Sends three data bits
1	0	0	0	B3	B2	B1	B0	Sends four data bits
0	0	0	B4	B3	B2	B1	B0	Sends five data bits

D7 Data Terminal Ready—when set, this bit forces the $\overline{DTR}$ pin active (low). When reset, this bit forces the $\overline{DTR}$ pin inactive (high).

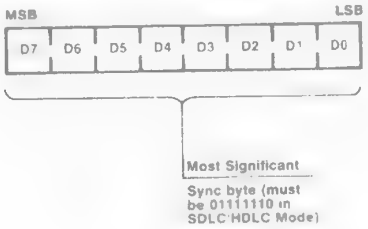
Write Register 6 (WR6):



WR6

D7–D0 Sync/Address—this register contains the transmit sync character in Monosync mode, the low order 8 sync bits in Bisync mode, or the Address byte in SDLC mode.

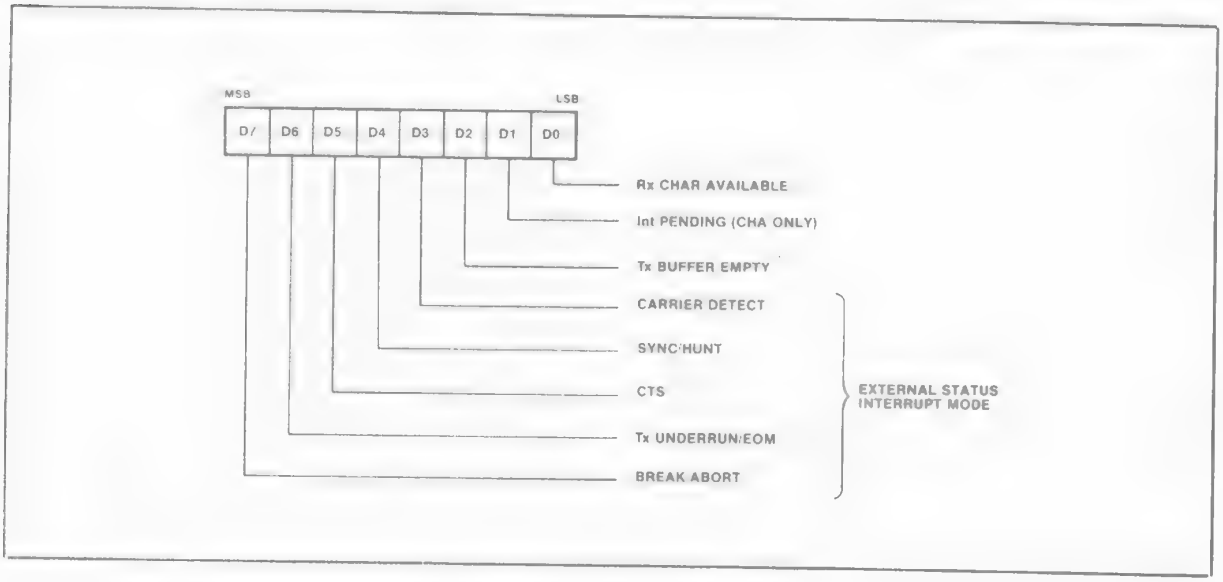
Write Register 7 (WR7):



WR7

D7–D0 Sync/Flag—this register contains the receive sync character in Monosync mode, the high order 8 sync bits in Bisync mode, or the Flag character (01111110) in SDLC mode. WR7 is not used in External Sync mode.

Read Register 0 (RR0):



RR0

D0 Receive Character Available—this bit is set when the receive FIFO contains data and is reset when the FIFO is empty.

D1 Interrupt Pending*—This Interrupt-Pending bit is reset when an EOI command is issued and there is no other interrupt request pending at that time.

D2 Transmit Buffer Empty—This bit is set whenever the transmit buffer is empty except when CRC characters are being sent in a synchronous mode. This bit is reset when the transmit buffer is loaded. This bit is set after an MPSC reset.

D3 Carrier Detect—This bit contains the state of the CD pin at the time of the last change of any of the External/Status bits ($\overline{CD}$, CTS, Sync/Hunt, Break/Abort, or Tx Underrun/EOM). Any change of state of the $\overline{CD}$ pin causes the CD bit to be latched and causes an External/Status interrupt. This bit indicates current state of the $\overline{CD}$ pin immediately following a Reset External/Status Interrupt command.

*In vector mode this bit is set at the falling edge of the second INTA in an INTA cycle for an internal interrupt request. In non-vector mode, this bit is set at the falling edge of RD input after pointer 2 is specified. This bit is always zero in Channel B.

D4 Sync/Hunt—In asynchronous modes, the operation of this bit is similar to the CD status bit, except that Sync/Hunt shows the state of the $\overline{SYNDET}$ input. Any High-to-Low transition on the $\overline{SYNDET}$ pin sets this bit, and causes an External/Status interrupt (if enabled). The Reset External/Status Interrupt command is issued to clear the interrupt. A Low-to-High transition clears this bit and sets the External/Status interrupt. When the External/Status interrupt is set by the change in state of any other input or condition, this bit shows the inverted state of the $\overline{SYNDET}$ pin at time of the change. This bit must be read immediately following a Reset External/Status Interrupt command to read the current state of the $\overline{SYNDET}$ input.

In the External Sync mode, the Sync/Hunt bit operates in a fashion similar to the Asynchronous mode, except the Enter Hunt Mode control bit enables the external sync detection logic. When the External Sync Mode and Enter Hunt Mode bits are set (for example, when the receiver is enabled following a reset), the $\overline{SYNDET}$ input must be held High by the external logic until external character synchronization is achieved. A High at the $\overline{SYNDET}$ input holds the Sync/Hunt status in the reset condition.

When external synchronization is achieved, SYNDET must be driven Low on the second rising edge of RxC after the rising edge of RxC on which the last bit of the sync character was received. In other words, after the sync pattern is detected, the external logic must wait for two full Receive Clock cycles to activate the SYNDET input. Once SYNDET is forced Low, it is good practice to keep it Low until the CPU informs the external sync logic that synchronization has been lost or a new message is about to start. The High-to-Low transition of the SYNDET output sets the Sync/Hunt bit, which sets the External/Status interrupt. The CPU must clear the interrupt by issuing the Reset External/Status Interrupt Command.

When the SYNDET input goes High again, another External/Status interrupt is generated that must also be cleared. The Enter Hunt Mode control bit isset whenever character synchronization is lost or the end of message is detected. In this case, the MPSC again looks for a High-to-Low transition on the SYNDET input and the operation repeats as explained previously. This implies the CPU should also inform the external logic that character synchronization has been lost and that the MPSC is waiting for SYNDET to become active.

In the Monosync and Bisync Receive modes, the Sync/Hunt status bit is initially set to 1 by the Enter Hunt Mode bit. The Sync/Hunt bit is reset when the MPSC establishes character synchronization. The High-to-Low transition of the Sync/Hunt bit causes an External/Status interrupt that must be cleared by the CPU issuing the Reset External/Status Interupt command. This enables the MPSC to detect the next transition of other External/Status bits.

When the CPU detects the end of message or that character synchronization is lost, it sets the Enter Hunt Mode control bit, which sets the Sync/Hunt bit to 1. The Low-to-High transition of the Sync/Hunt bit sets the External/Status Interrupt, which must also be cleared by the Reset External/Status Interrupt Command. Note that the SYNDET pin acts as an output in this mode, and goes low every time a sync pattern is detected in the data stream.

In the SDLC mode, the Sync/Hunt bit is initially set by the Enter Hunt mode bit, or when the receiver is disabled. In any case, it is reset to 0 when the opening flag of the first frame is detected by the MPSC. The External/Status interrupt is also generated, and should be handled as discussed previously .

Unlike the Monosync and Bisync modes, once the Sync/Hunt bit is reset in the SDLC mode, it does not need to be set when the end of message is detected. The MPSC automatically maintains synchronization. The only way the Sync/Hunt bit can be set again is by the Enter Hunt Mode bit, or by disabling the receiver.

D5 Clear to Send—this bit contains the inverted state of the CTS pin at the time of the last change of any of the External/Status bits (CD, CTS, Sync/Hunt, Break/Abort, or Tx Underrun/EOM). Any change of state of the CTS pin causes the CTS bit to be latched and causes an External/Status interrupt. This bit indicates the inverse of the current state of the CTS pin immediately following a Reset External/Status Interrupt command.

D6 Transmitter Underrun/End of Message—this bit is in a set condition following a reset (internal or external). The only command that can reset this bit is the Reset Transmit Underrun/EOM Latch command (WR0, D_6 and D_7). When the Transmit Underrun condition occurs, this bit is set, which causes the External/Status Interrupt which must be reset by issuing a Reset External/Status command (WR0; command 2).

D7 Break/Abort—in the Asynchronous Receive mode, this bit is set when a Break sequence (null character plus framing error) is detected in the data stream. The External/Status interrupt, if enabled, is set when break is detected. The interrupt service routine must issue the Reset External/Status Interrupt command (WR0, Command 2) to the break detection logic so the Break sequence termination can be recognized.

SDLC Residue Code Table (I Field Bits in 2 Previous Bytes)

	8 bits/char		7 bits/char		6 bits/char		5 bits/char	
RR1 D3, D2, D1	Previous Byte	2nd Prev. Byte	Previous Byte	2nd Prev. Byte	Previous Byte	2nd Prev. Byte	Previous Byte	2nd Prev. Byte
1 0 0	0	3						
0 1 0	0	4			0	6		
1 1 0	0	5						
0 0 1	0	6					0	5
1 0 1	0	7						
0 1 1	0	8						
1 1 1	1	[illegible]						
0 0 0	2	8	0	7				

The Break/Abort bit is reset when the termination of the Break sequence is detected in the incoming data stream. The termination of the Break sequence also causes the External/Status interrupt to be set. The Reset External/Status Interrupt command must be issued to enable the break detection logic to look for the next Break sequence. A single extraneous null character is present in the receiver after the termination of a break; it should be read and discarded.

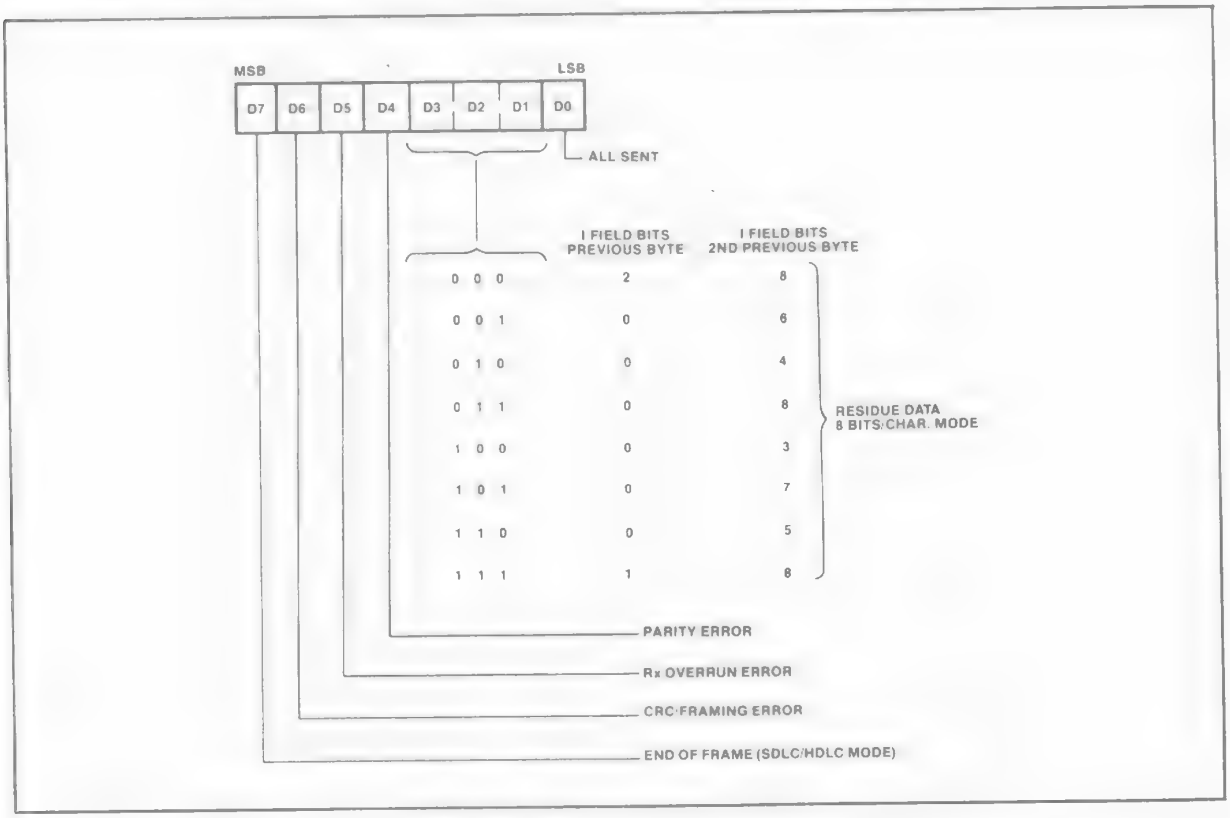
In the SDLC Receive mode, this status bit is set by the detection of an Abort sequence (seven or more 1's). The External/Status interrupt is handled the same way as in the case of a Break. The Break/Abort bit is not used in the Synchronous Receive mode.

D0 All sent—this bit is set when all characters have been sent, in asynchronous modes. It is reset when characters are in the transmitter, in asynchronous modes. In synchronous modes, this bit is always set.

D3, D2, D1 Residue Codes—bit synchronous protocols allow I-fields that are not an integral number of characters. Since transfers from the MPSC to the CPU are character oriented, the residue codes provide the capability of receiving leftover bits. Residue bits are right justified in the last two data bytes received.

D4 Parity Error—If parity is enabled, this bit is set for received characters whose parity does not match the programmed sense (Even/Odd). This bit is latched. Once an error occurs, it remains set until the Error Reset command is written.

Read Register 1 (RR1): (Special Receive Condition Mode)

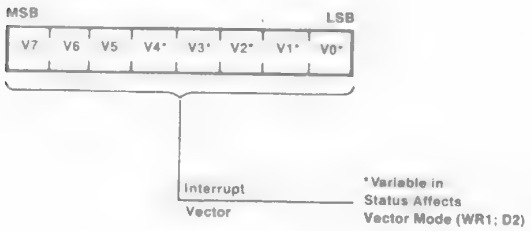


D5 Receive Overrun Error—this bit indicates that the receive FIFO has been overloaded by the receiver. The last character in the FIFO is overwritten and flagged with this error. Once the overwritten character is read, this error condition is latched until reset by the Error Reset command. If the MPSC is in the status affects vector mode, the overrun causes a special Receive Condition Vector.

D6 CRC/Framing Error—In async modes, a one in this bit indicates a receive framing error. In synchronous modes, a one in this bit indicates that the calculated CRC value does not match the last two bytes received. It can be reset by issuing an Error Reset command.

D7 End of Frame—this bit is valid only in SDLC mode. A one indicates that a valid ending flag has been received. This bit is reset either by an Error Reset command or upon reception of the first character of the next frame.

Read Register 2 (RR2):



RR2 Channel B

D7–D0 Interrupt vector—contains the interrupt vector programmed into WR2. If the status affects vector mode is selected, it contains the modified vector. (See WR2) RR2 contains the modified vector for the highest priority interrupt pending. If no interrupts are pending, the variable bits in the vector are set to one.

SYSTEM INTERFACE

General

The MPSC to Microprocessor System interface can be configured in many flexible ways. The basic interface types are polled, wait, interrupt driven, or direct memory access driven.

Polled operation is accomplished by repetitively reading the status of the MPSC, and making decisions based on that status. The MPSC can be polled at any time.

Wait operation allows slightly faster data throughput for the MPSC by manipulating the Ready input to the microprocessor. Block Read or Write Operations to the MPSC are started at will by the microprocessor and the MPSC deactivates its RDY signal if it is not yet ready to transmit the new byte, or if reception of new byte is not completed.

Interrupt driven operation is accomplished via an internal or external interrupt controller. When the MPSC requires service, it sends an interrupt request signal to the microprocessor, which responds with an interrupt acknowledge signal. When the internal or external interrupt controller receives the acknowledge, it vectors the microprocessor to a service routine, in which the transaction occurs.

DMA operation is accomplished via an external DMA controller. When the MPSC needs a data transfer, it request a DMA cycle from the DMA controller. The DMA controller then takes control of the bus and simultaneously does a read from the MPSC and a write to memory or vice-versa.

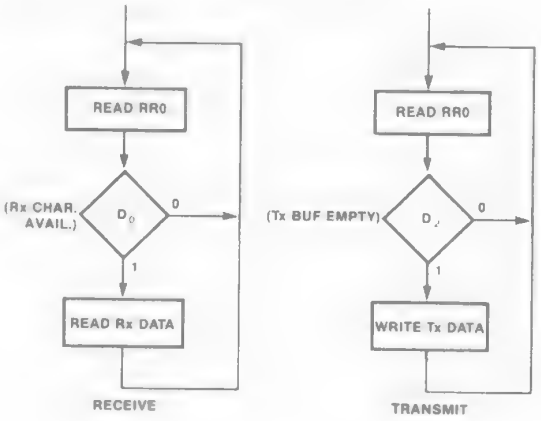
The following section describes the many configurations of these basic types of system interface techniques for both serial channels.

Polled Operation:

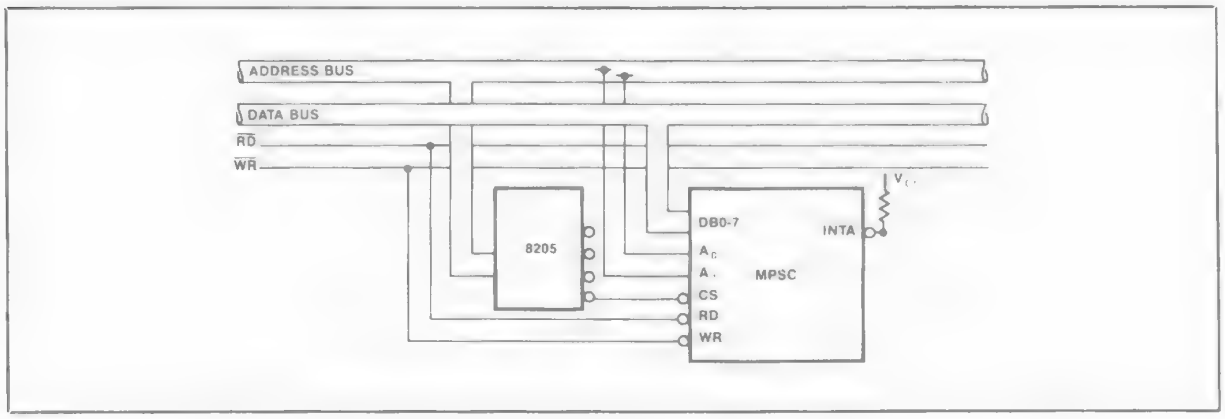
In the polled mode, the CPU must monitor the desired conditions within the MPSC by reading the appropriate bits in the read registers. All data available, status, and error conditions are represented by the appropriate bits in read registers 0 and 1 for channels A and B.

There are two ways in which the software task of monitoring the status of the MPSC has been reduced. One is the "ORing" of all conditions into the Interrupt Pending bit. (RR0; D1 channel A only). This bit is set when the MPSC requires service, allowing the CPU to monitor one bit instead of four status registers. The other is available when the "status-affects-vector" mode is selected. By reading RR2 Channel B, the CPU can read a vector who's value will indicate that one or more of group of conditions has occurred, narrowing the field of possible conditions. See WR2 and RR2 in the Detailed Command Description section.

Software Flow, Polled Operation



Hardware Configuration, Polled Operation



WAIT OPERATION:
Wait Operation is intended to facilitate data transmission or reception using block move operations. If a block of data is to be transmitted, for example, the CPU can execute a String I/O instruction to the MPSC. After writing the first byte, the CPU will attempt to write a second byte immediately as is the case of block move. The MPSC forces the RDY signal low which inserts wait states in the CPU's write cycle until the transmit buffer is ready to accept a new byte. At that time, the RDY signal is high allowing the CPU to finish the write cycle. The CPU then attempts the third write and the process is repeated.

Similar operation can be programmed for the receiver. During initialization, wait on transmit (WR2; D5 = 0) or wait on receive (WR1; D5 = 1) can be selected.The wait operation can be enabled/disabled by setting/resetting the Wait Enable Bit (WR1; D7).

CAUTION: ANY CONDITION THAT CAN CAUSE THE TRANSMITTER TO STOP (EG, CTS GOES INACTIVE) OR THE RECEIVER TO STOP (EG, RX DATA STOPS) WILL CAUSE THE MPSC TO HANG THE CPU UP IN WAIT STATES UNTIL RESET. EXTREME CARE SHOULD BE TAKEN WHEN USING THIS FEATURE.

INTERRUPT DRIVEN OPERATION:
The MPSC can be programmed into several interrupt modes: Non-Vectored, 8085 vectored, and 8088/86 vectored. In both vectored modes, multiple MPSC's can be daisy-chained.

In the vectored mode, the MPSC responds to an interrupt acknowledge sequence by placing a call instruction (8085 mode) and interrupt vector (8085 and 8088/86 mode) on the data bus.

The MPSC can be programmed to cause an interrupt due to up to 14 conditions in each channel. The status of these interrupt conditions is contained in Read Registers 0 and 1. These 14 conditions are all directed to cause 3 different types of internal interrupt request for each channel: receive/interrupts, transmit interrupts and external/status interrupts (if enabled).

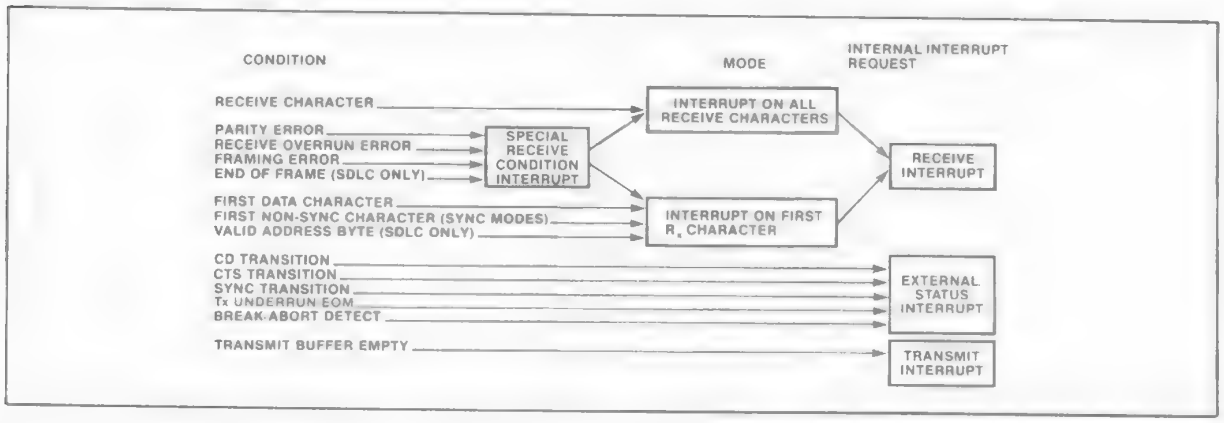
This results in up to 6 internal interrupt request signals. The priority of those signals can be programmed to one of two fixed modes:

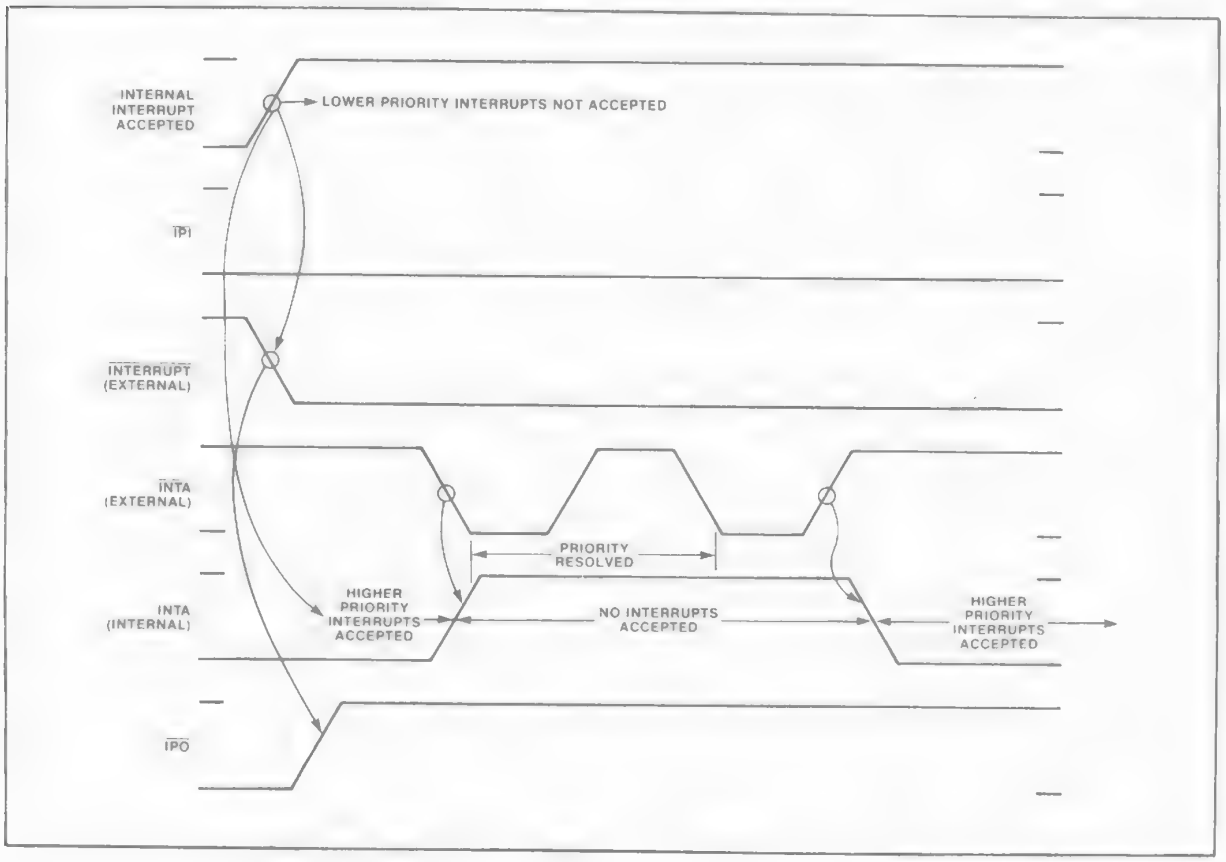
Highest Priority					Lowest Priority
RxA	RxB	TxA	TxB	ExTA	ExTB
RxA	TxA	RxB	TxB	ExTA	ExTB

The interrupt priority resolution works differently for vectored and non-vectored modes.

PRIORITY RESOLUTION: VECTORED MODE
Any interrupt condition can be accepted internally to the MPSC at any time, unless the MPSC's internal INTA signal is active, unless a higher priority interrupt is currently accepted, or if $\overline{IPI}$ is inactive (high). The MPSC's internal INTA is set on the leading (falling) edge of the first External $\overline{INTA}$ pulse and reset on the trailing (rising) edge of the second External $\overline{INTA}$ pulse. After an interrupt is accepted internally, an External $\overline{INT}$ request is generated and the $\overline{IPO}$ goes inactive. $\overline{IPO}$ and $\overline{IPI}$ are used for daisy-chaining MPSC's together.

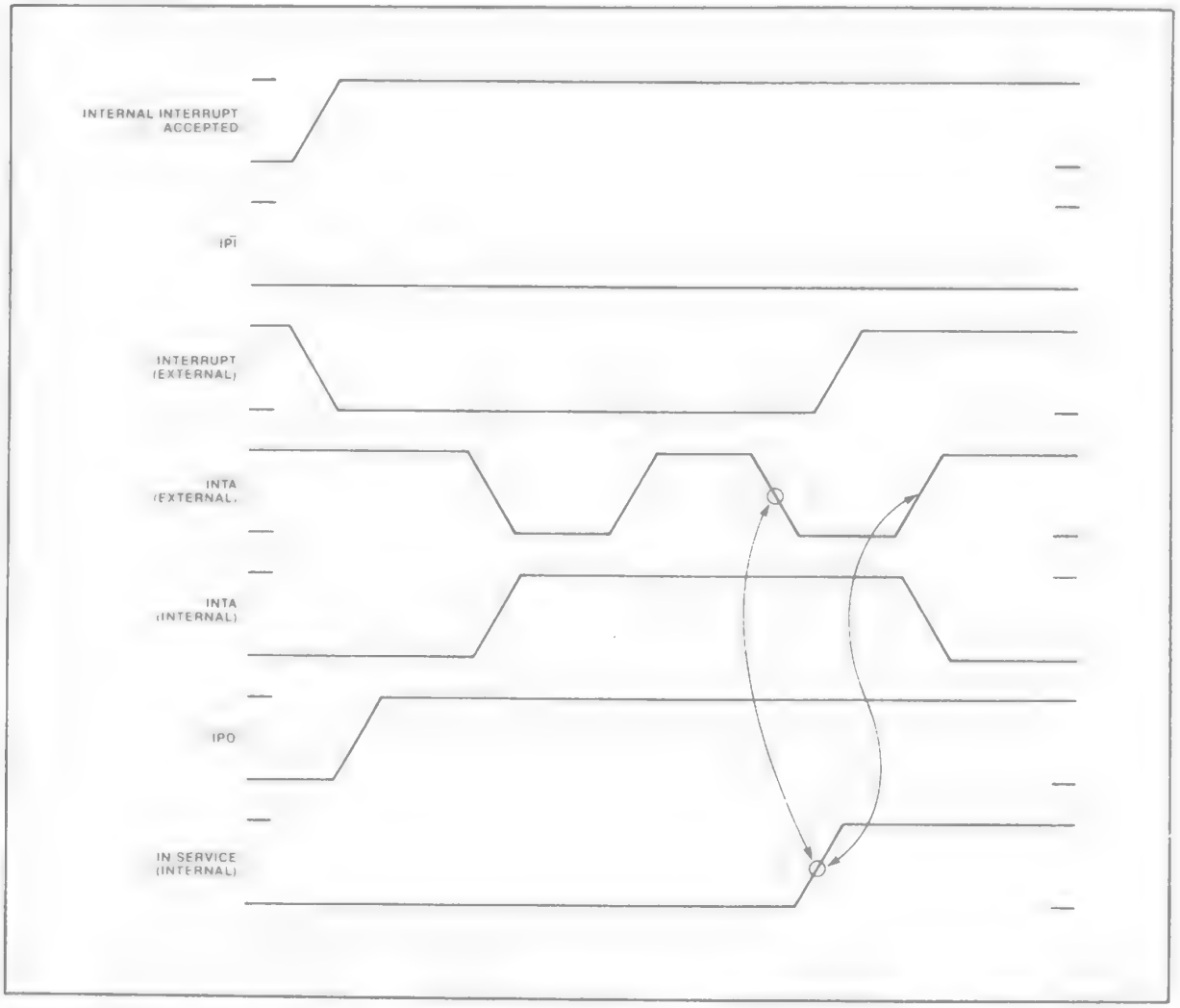
Interrupt Condition Grouping





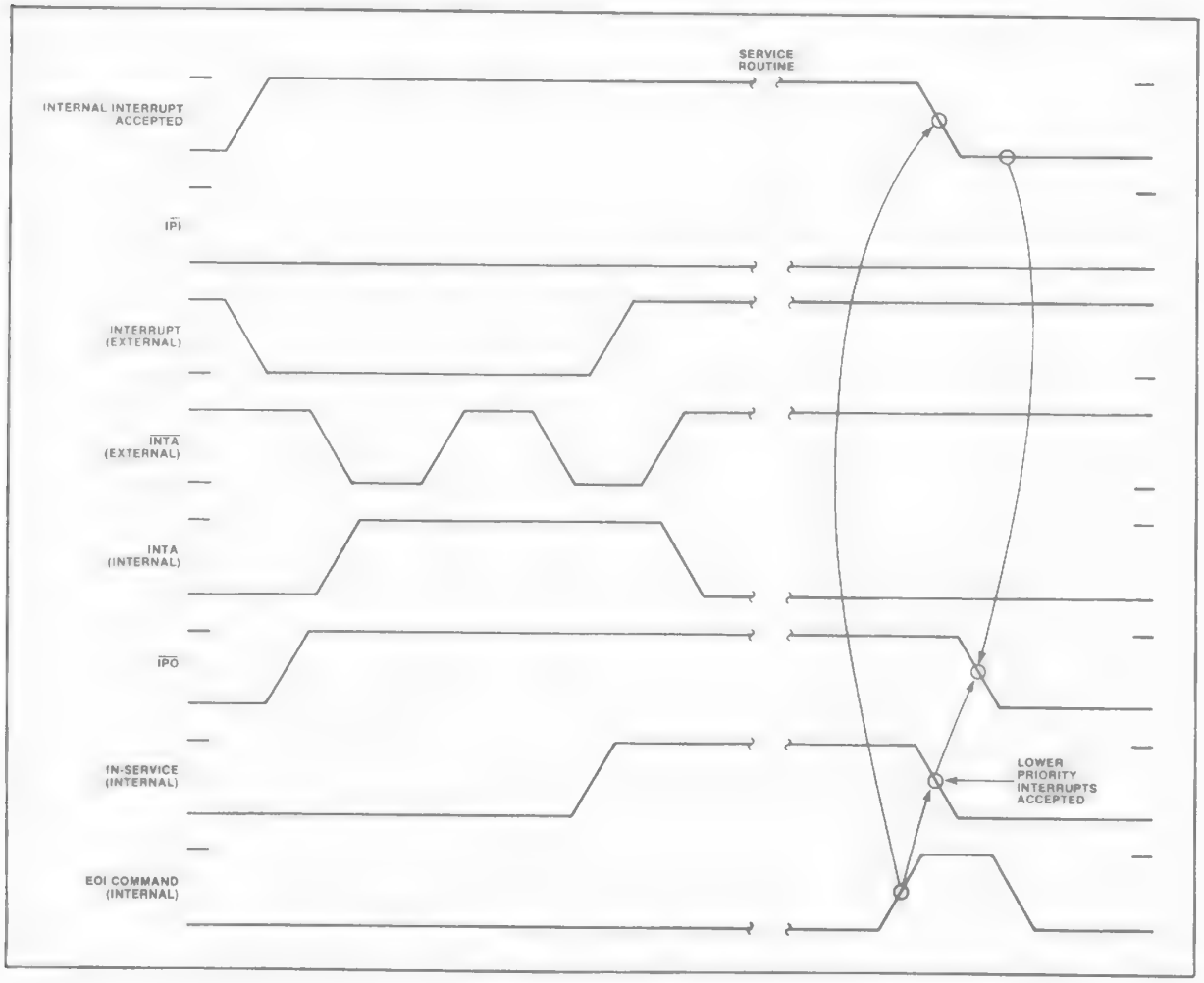
The MPSC's internal INTA is set on the leading (falling) edge of the first external $\overline{\text{INTA}}$ pulse, and reset on the trailing (rising) edge of the second external $\overline{\text{INTA}}$ pulse. After an interrupt is accepted internally, an external $\overline{\text{INT}}$ request is generated and $\overline{\text{IPO}}$ goes inactive (high). $\overline{\text{IPO}}$ and $\overline{\text{IPI}}$ are used for daisy-chaining MPSC's together.

In-Service Timing



Each of the six interrupt sources has an associated In-Service latch. After priority has been resolved, the highest priority In-Service latch is set. After the In-Service latch is set, the $\overline{INT}$ pin goes inactive (high).

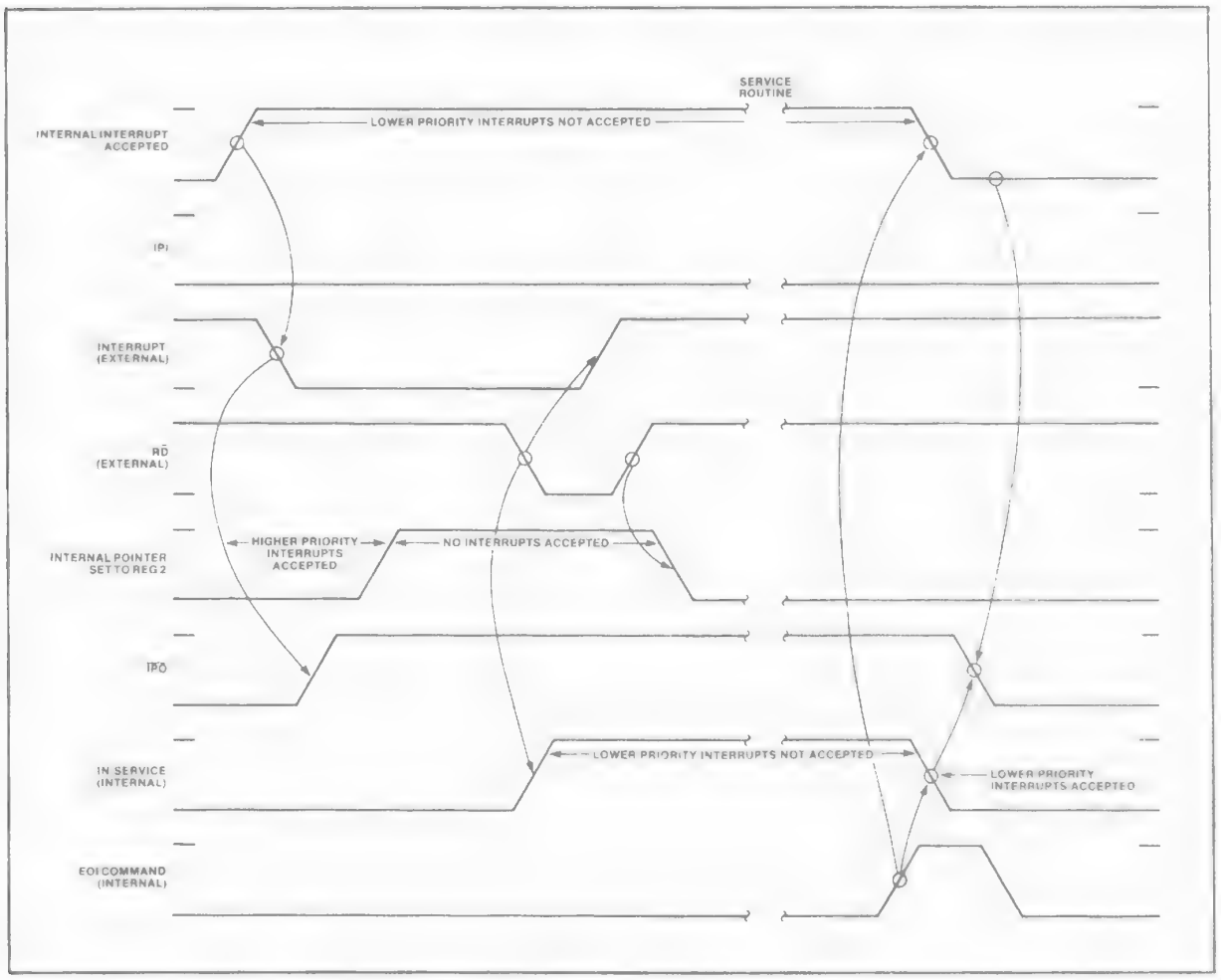
EOI Command Timing



Lower priority interrupts are not accepted internally while the In-Service latch is set. However, higher priority interrupts are accepted internally and a new external $\overline{INT}$ request is generated. If the CPU responds with a new INTA sequence, the MPSC will respond as before, suspending the lower priority interrupt.

After the interrupt is serviced, the End-of-Interrupt (EOI) command should be written to the MPSC. This command will cause an internal pulse that is used to reset the In-Service Latch which allows service for lower priority interrupts in the daisy-chain to resume, provided a new INTA sequence does not start for a higher priority interrupt (higher than the highest under service). If there is no interrupt pending internally, the $\overline{IPO}$ follows $\overline{IPI}$.

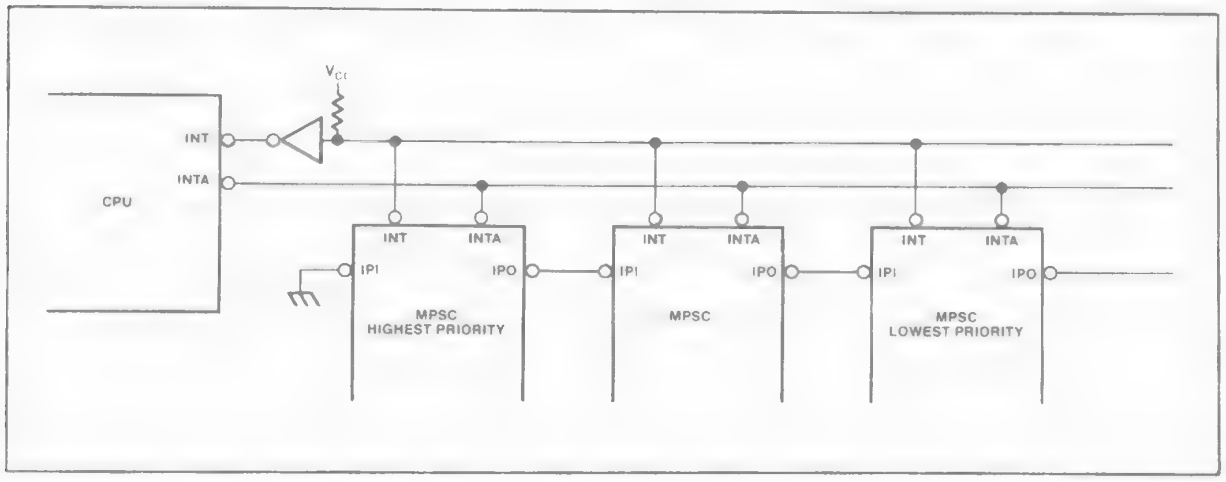
Non-Vectored Interrupt Timing



PRIORITY RESOLUTION: NON-VECTORED MODE

In non-vectored mode, the MPSC does not respond to interrupt acknowledge sequences. The INTA input (pin 27) must be pulled high for proper operation. The MPSC should be programmed to the Status-Affects-Vector mode, and the CPU should read RR2 (Ch. B) in its service routine to determine which interrupt requires service.

In this case, the internal pointer being set to RR2 provides the same function as the internal INTA signal in the vectored mode. It inhibits acceptance of any additional internal interrupts and its leading edge starts the interrupt priority resolution circuit. The interrupt priority resolution is ended by the leading edge of the read signal used by the CPU to retrieve the modified vector. The leading edge of read sets the In-Service latch and forces the external $\overline{INT}$ output inactive (high). The internal pointer is reset to zero after the trailing edge of the read pulse.



Note that if RR2 is specified but not read, no internal interrupts, regardless of priority, are accepted.

DAISY CHAINING MPSC:

In the vectored interrupt mode, multiple MPSC's can be daisy-chained on the same $\overline{INT}$, $\overline{INTA}$ signals. These signals, in conjunction with the $\overline{IPI}$ and $\overline{IPO}$ allow a daisy-chain-like interrupt resolution scheme. This scheme can be configured for either 8085 or 8086/88 based system.

In either mode, the same hardware configuration is called for. The $\overline{INT}$ request lines are wire-OR'ed together at the input of a TTL inverter which drives the INT pin of the CPU. The $\overline{INTA}$ signal from the CPU drives all of the daisy-chained MPSC's.

The MPSC drives $\overline{IPO}$ (Interrupt Priority Output) inactive (high) if $\overline{IPI}$ (Interrupt Priority Input) is inactive (high), or if the MPSC has an interrupt pending.

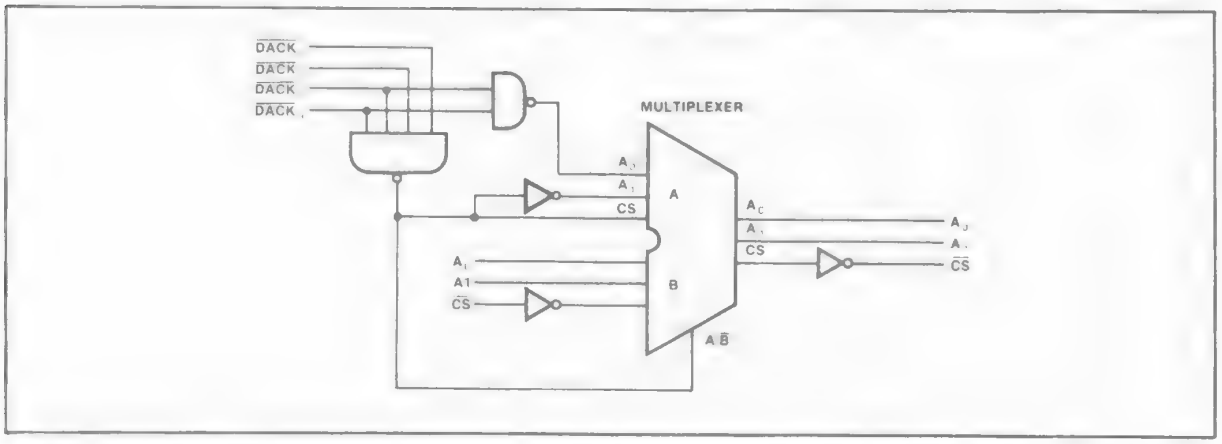
The $\overline{IPO}$ of the highest priority MPSC is connected to the $\overline{IPI}$ of the next highest priority MPSC, and so on.

If $\overline{IPI}$ is active (low), the MPSC knows that all higher priority MPSC's have no interrupts pending. The $\overline{IPI}$ pin of the highest priority MPSC is strapped active (low) to ensure that it always has priority over the rest.

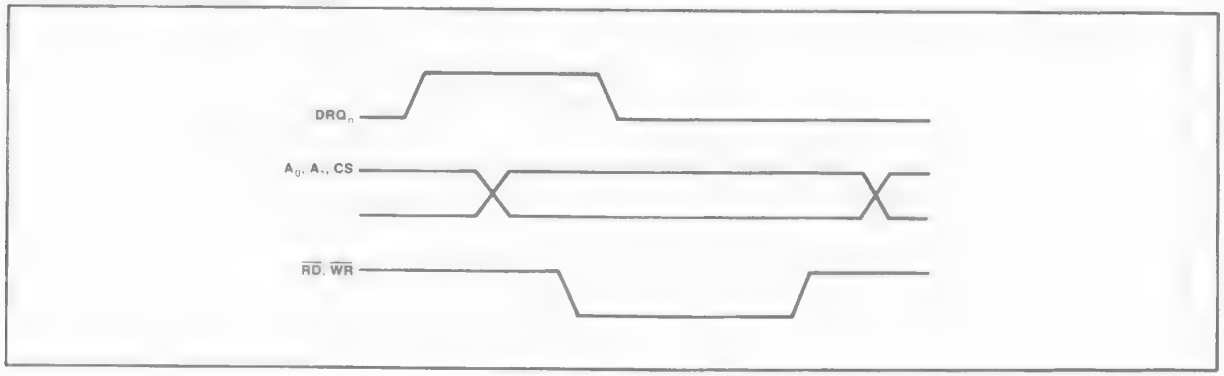
MPSC's Daisy-chained on an 8088/86 CPU should be programmed to the 8088/86 Interrupt mode (WR2; D4, D3 (Ch. A). MPSC's Daisy-chained on an 8085 CPU should be programmed to 8085 interrupt mode 1 if it is the highest priority MPSC. In this mode, the highest priority MPSC issues the CALL instruction during the first INTA cycle, and the interrupting MPSC provides the interrupt vector during the following $\overline{INTA}$ cycles. Lower priority MPSC's should be programmed to 8085 interrupt mode 2.

MPSC's used alone in 8085 systems should be programmed to 8085 mode 1 interrupt operation.

DMA Acknowledge Circuit



DMA Timing



DMA OPERATION

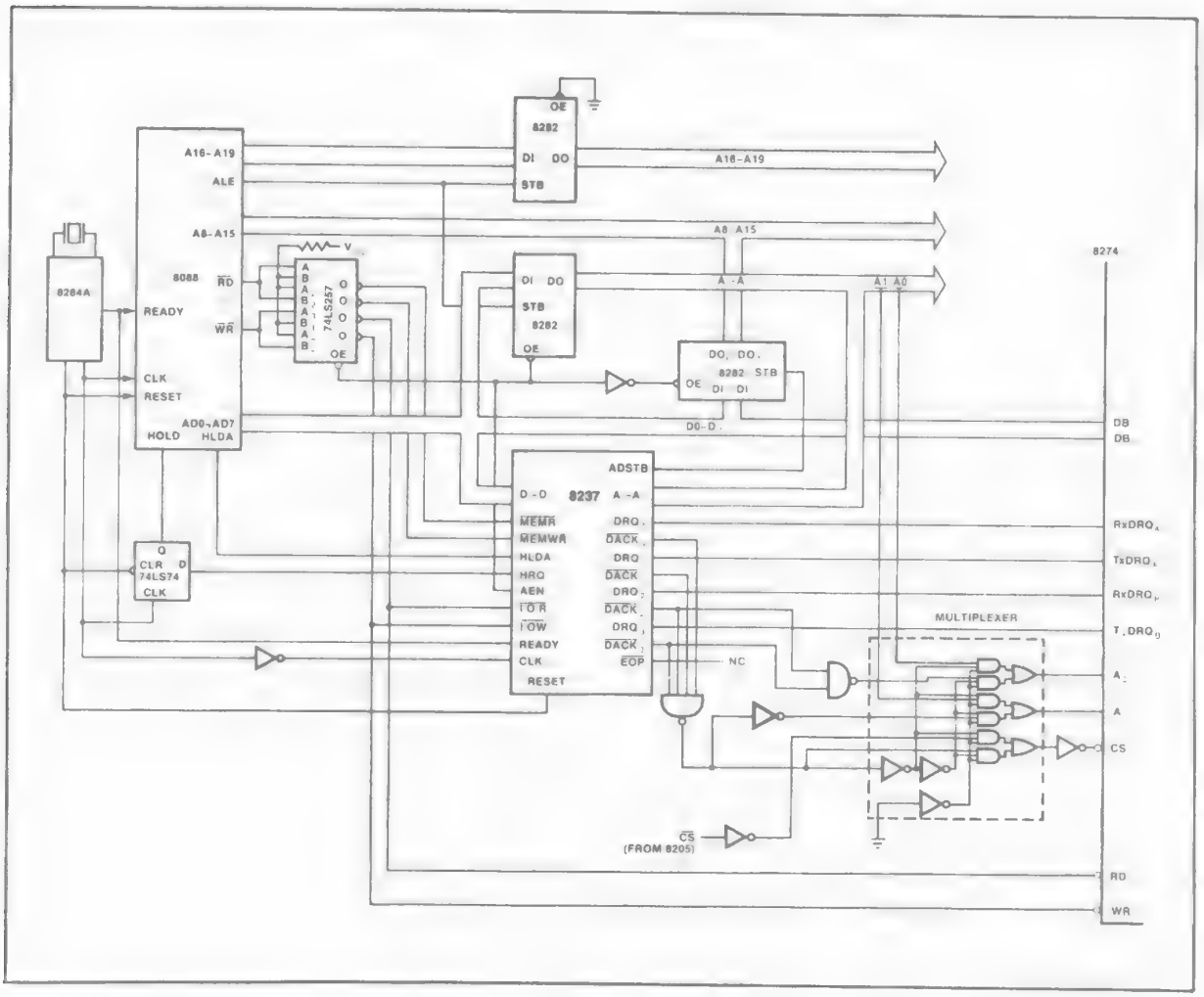
Each MPSC can be programmed to utilize up to four DMA channels: Transmit Channel A, Receive Channel A, Transmit Channel B, Receive Channel B. Each DMA Channel has an associated DMA Request line. Acknowledgement of a DMA cycle is done via normal data read or write cycles. This is accomplished by encoding the $\overline{DACK}$ signals to generate A_0, A_1, and $\overline{CS}$ signals, and multiplexing them with the normal A_0, A_1, and $\overline{CS}$ signals.

PERMUTATIONS

Channels A and B can be used with different system interface modes. In all cases it is impossible to poll the MPSC. The following table shows the possible permutations of interupt, wait, and DAM modes for channels A and B. Bits D_1, D_0 of WR2 Ch. A determine these permutations.

Permutation WR2 Ch. A D_1 D_0	Channel A	Channel B
0 0	Wait Interrupt Polled	Wait Interrupt Polled
0 1	DMA Polled	Interrupt Polled
1 0	DMA Polled	DMA Polled

D1, D0 = 1, 1 is illegal.


8282
OE
DI
DO
STB
A16-A19
ALE
A8-A15
8088
RD
WR
READY
CLK
RESET
AD0-AD7
HOLD
HLDA
8284A
74LS257
V
8237
ADSTB
D-D
A-A
MEMR
MEMWR
HLDA
HRQ
AEN
IOR
IOW
READY
CLK
RESET
DRQ
DACK
EOP
NC
74LS74
CLR
D
Q
CS
(FROM 8205)
MULTIPLEXER
8274
DB
RxDRQ
TxDRQ
A
CS
RD
WR

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature
Under Bias ..... 0°C to +70°C
Storage Temperature
(Ceramic Package) ..... −65°C to +150°C
(Plastic Package) ..... −40°C to +125°C
Voltage On Any Pin With
Respect to Ground ..... −0.5V to +7.0V
Power Dissipation 1.5W

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C; V_{CC} = +5V ±10%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	+0.8	V	
V_{IH}	Input High Voltage	+2.0	V_{CC} +0.5	V	
V_{OL}	Output Low Voltage		+0.45	V	I_{OL} = 2.0mA
V_{OH}	Output High Voltage	+2.4		V	I_{OH} = −200μA
I_{IL}	Input Leakage Current		−10	μA	V_{IN} = V_{CC} to 0V
I_{OL}	Output Leakage Current		−10	μA	V_{OUT} = V_{CC} to 0V
I_{CC}	V_{CC} Supply Current		180	mA	

CAPACITANCE (T_A = 25°C; V_{CC} = GND = 0V)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
C_{IN}	Input Capacitance		10	pF	f_c = 1 MHz;
C_{OUT}	Output Capacitance		15	pF	Unmeasured
$C_{I/O}$	Input/Output Capacitance		20	pF	pins returned to GND

A.C. CHARACTERISTICS (T_A = 0°C to 70°C; V_{CC} = +5V ±10%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
t_{CY}	CLK Period	250	4000	ns	
t_{CL}	CLK Low Time	105	2000	ns	
t_{CH}	CLK High Time	105	2000	ns	
t_r	CLK Rise Time	0	30	ns	
t_f	CLK Fall Time	0	30	ns	
t_{AR}	A0, A1 Setup to $\overline{RD}\downarrow$	0		ns	
t_{AD}	A0, A1 to Data Output Dlay		200	ns	C_L=150 pf
t_{RA}	A0, A1 Hold After $\overline{RD}\uparrow$	0		ns	
t_{RD}	$\overline{RD}\downarrow$ to Data Output Delay		200	ns	C_L=150 pf
t_{RR}	$\overline{RD}$ Pulse Width	250		ns	
t_{DF}	Output Float Delay		120	ns	
t_{AW}	$\overline{CS}$, A0, A1 Setup to $\overline{WR}\downarrow$	0		ns	
t_{WA}	$\overline{CS}$, A0, A1 Hold after $\overline{WR}\uparrow$	0		ns	
t_{WW}	$\overline{WR}$ Pulse Width	250		ns	
t_{DW}	Data Setup to $\overline{WR}\uparrow$		150	ns	
t_{WD}	Data Hold After $\overline{WR}\uparrow$	0		ns	
t_{PI}	$\overline{IPI}$ Setup to $\overline{INTA}\downarrow$	0		ns	
t_{IP}	$\overline{IPI}$ Hold after $\overline{INTA}\uparrow$	0		ns	
t_{II}	$\overline{INTA}$ Pulse Width	250		ns	
t_{IAPO}	$\overline{INTA}\downarrow$ to $\overline{IPO}$ Delay		200	ns	
t_{PIPO}	$\overline{IPI}\downarrow$ to $\overline{IPO}$ Delay		100	ns	
t_{ID}	$\overline{INTA}\downarrow$ to Data Output Deay		200	ns	
t_{CQ}	$\overline{RD}$ or $\overline{WR}$ to DRQ$\downarrow$		150	ns	
t_{RV}	Recovery Time Between Controls	300		ns	
t_{CW}	$\overline{CS}$, A0, A1 to $\overline{RDY_A}$ or $\overline{RDY_B}$ Delay		120	ns	
t_{DCY}	Data Clock Cycle	400		ns	
t_{DCL}	Data Clock Low Time	180		ns	
t_{DCH}	Data Clock High Time	180		ns	
t_{TD}	$\overline{TxC}$ to TxD Delay		300	ns	
t_{DS}	RxD Setup to $\overline{RxC}\uparrow$	0		ns	
t_{DH}	RxD Hold after $\overline{RxC}\uparrow$	140		ns	
t_{ITD}	$\overline{TxC}$ to $\overline{INT}$ Delay	4		tcy	
t_{IRD}	RxC to $\overline{INT}$ Delay	7	10	tcy	
t_{PL}	$\overline{CTS}$, $\overline{CD}$, $\overline{SYNDET}$ Low Time	200		ns	
t_{PH}	$\overline{CTS}$, $\overline{CD}$, $\overline{SYNDET}$ High Time	200		ns	
t_{IPD}	External $\overline{INT}$ from $\overline{CTS}$, $\overline{CD}$, $\overline{SYNDET}$		500	ns	

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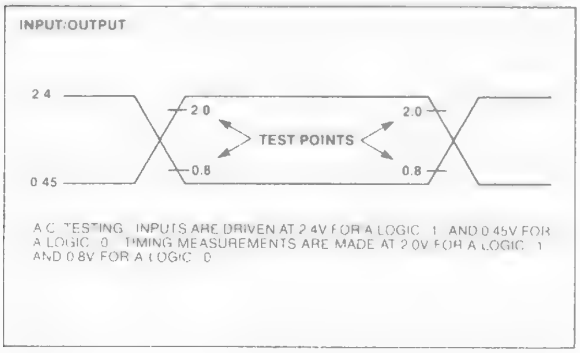
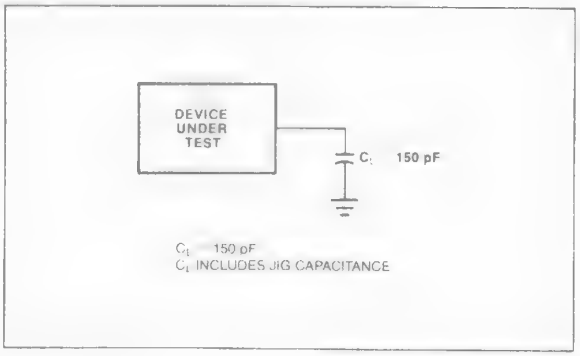
A.C. TESTING INPUT, OUTPUT WAVEFORM

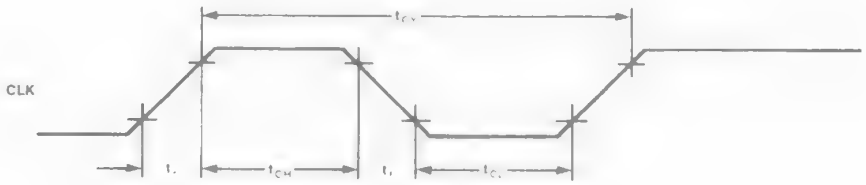


A.C. TESTING LOAD CIRCUIT

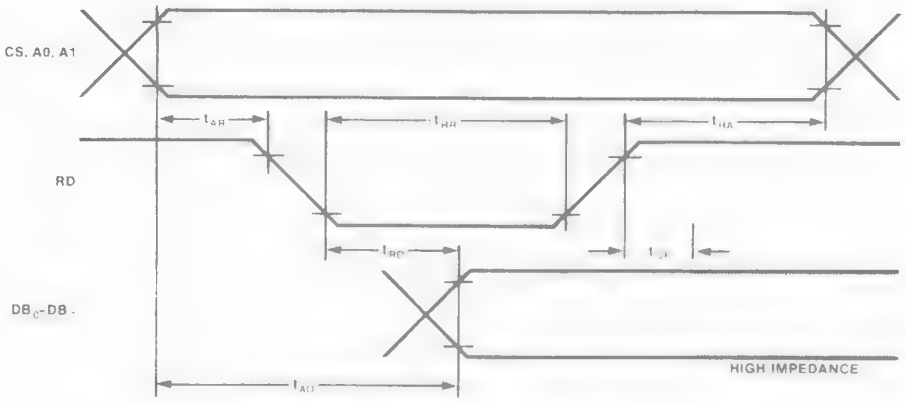


WAVEFORMS

CLOCK CYCLE

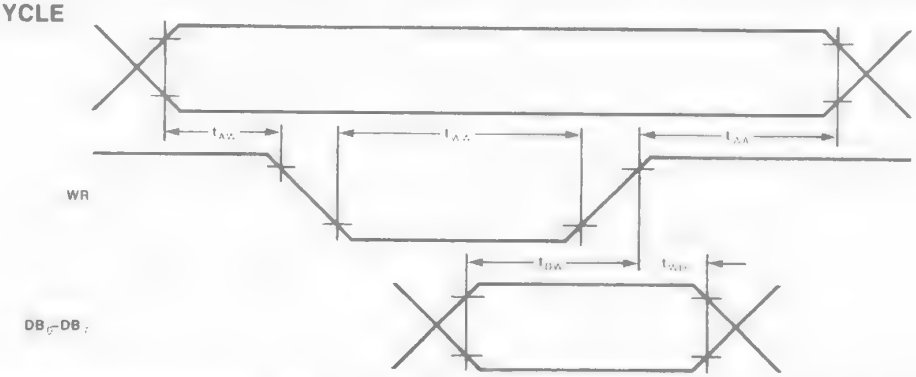


READ CYCLE

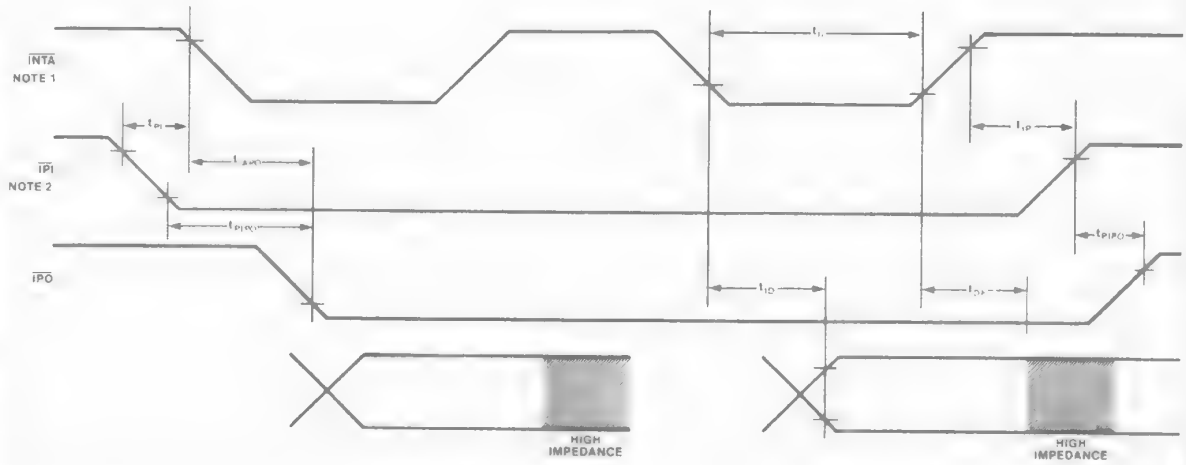


WAVEFORMS (Continued)

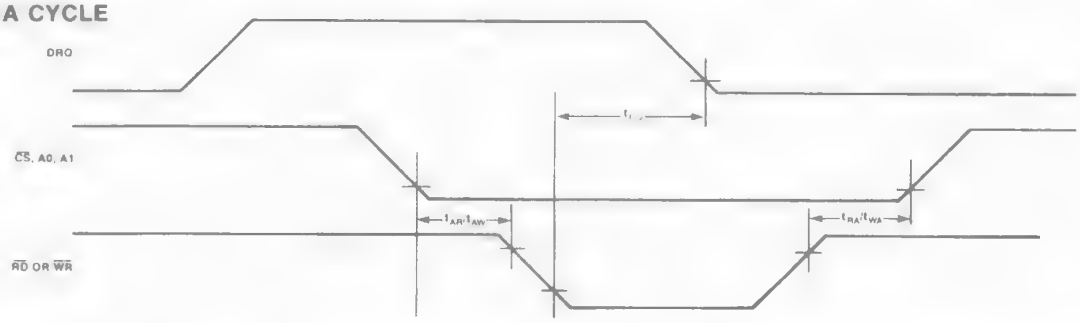
WRITE CYCLE



INTA CYCLE



DMA CYCLE

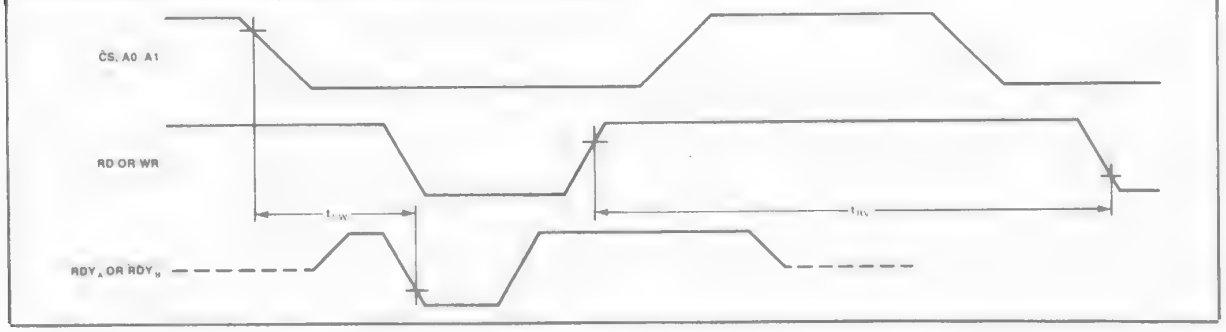


NOTES:
1. INTA signal acts as RD signal.
2. IPI signal acts as CS signal.

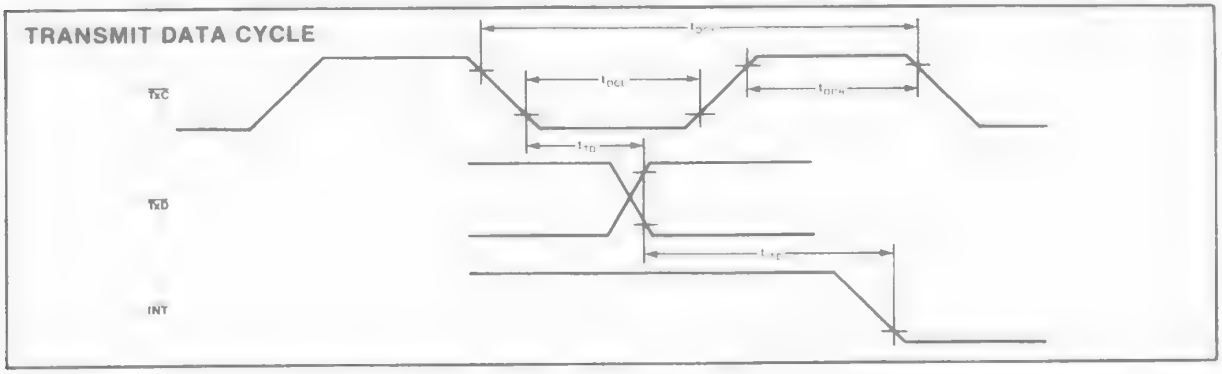
AFN-01701C

WAVEFORMS (Continued)

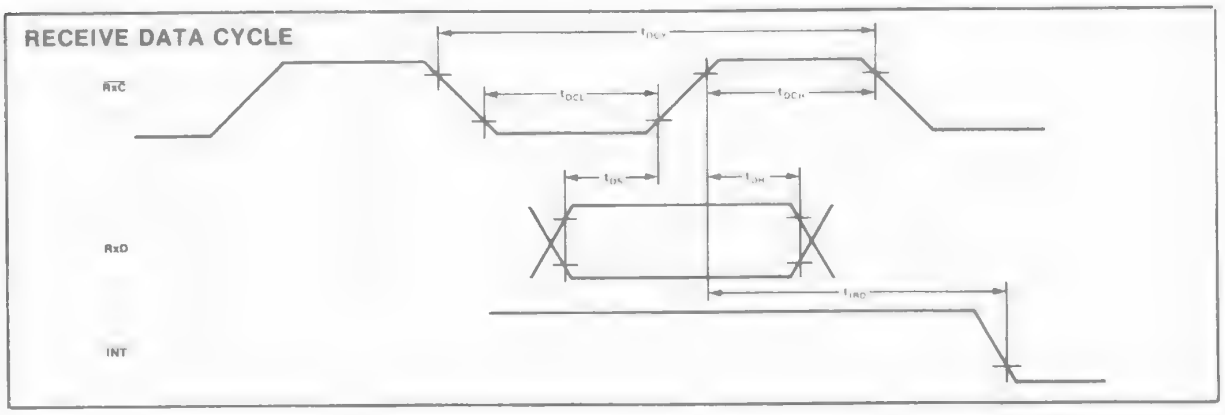
READ/WRITE CYCLE (SOFTWARE POLLED MODE)



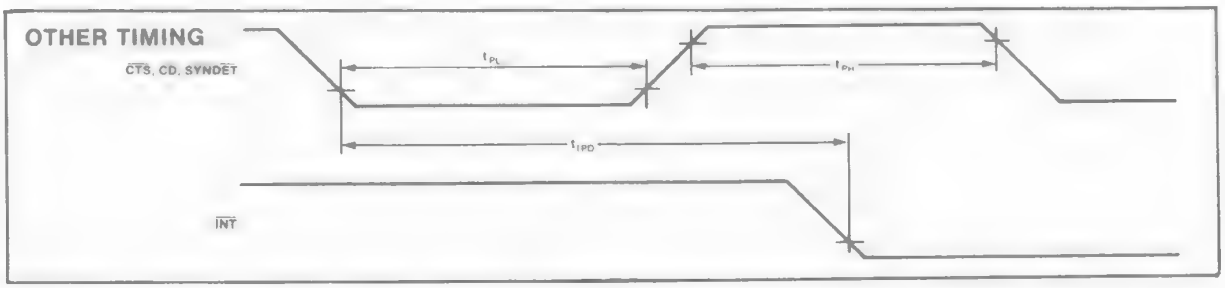
TRANSMIT DATA CYCLE



RECEIVE DATA CYCLE



OTHER TIMING



8275H
PROGRAMMABLE CRT CONTROLLER

- **Programmable Screen and Character Format**
- **6 Independent Visual Field Attributes**
- **11 Visual Character Attributes (Graphic Capability)**
- **Cursor Control (4 Types)**
- **Light Pen Detection and Registers**
- **MCS-51®, MCS-85®, iAPX 86, and iAPX 88 Compatible**
- **Dual Row Buffers**
- **Programmable DMA Burst Mode**
- **Single +5V Supply**
- **High Performance HMOS-II**

The Intel® 8275H Programmable CRT Controller is a single chip device to interface CRT raster scan displays with Intel® microcomputer systems. It is manufactured on Intel's advanced HMOS-II process. Its primary function is to refresh the display by buffering the information from main memory and keeping track of the display position of the screen. The flexibility designed in the 8275H will allow simple interface to almost any raster scan CRT display with a minimum of external hardware and software overhead.

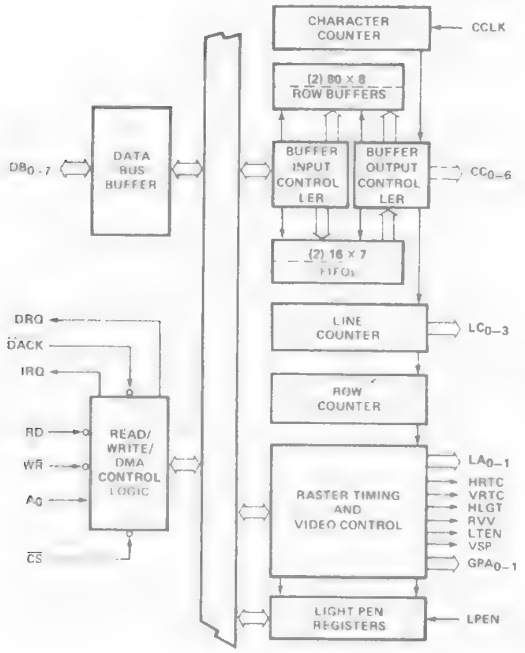


Figure 1. Block Diagram

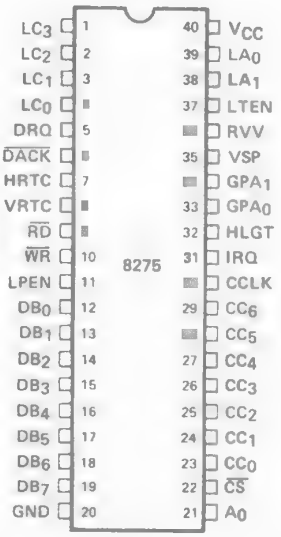


Figure 2. Pin Configuration

Intel Corporation Assumes No Responsibility for the Use of Any Circuitry Other Than Circuitry Embodied in an Intel Product. No Other Circuit Patent Licenses are Implied.
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APRIL 1982
ORDER NUMBER: 210464-001

Table 1. Pin Descriptions

Symbol	Pin No.	Type	Name and Function
LC_3 LC_2 LC_1 LC_0	1 2 3 4	O	**Line Count:** Output from the line counter which is used to address the character generator for the line positions on the screen.
DRQ	5	O	**DMA Request:** Output signal to the 8257 DMA controller requesting a DMA cycle.
$\overline{DACK}$	6	I	**DMA Acknowledge:** Input signal from the 8257 DMA controller acknowledging that the requested DMA cycle has been granted.
HRTC	7	O	**Horizontal Retrace:** Output signal which is active during the programmed horizontal retrace interval. During this period the VSP output is high and the LTEN output is low.
VRTC	8	O	**Vertical Retrace:** Output signal which is active during the programmed vertical retrace interval. During this period the VSP output is high and the LTEN output is low.
$\overline{RD}$	9	I	**Read Input:** A control signal to read registers.
$\overline{WR}$	10	I	**Write Input:** A control signal to write commands into the control registers or write data into the row buffers during a DMA cycle.
LPEN	11	I	**Light Pen:** Input signal from the CRT system signifying that a light pen signal has been detected.
DB_0 DB_1 DB_2 DB_3 DB_4 DB_5 DB_6 DB_7	12 13 14 15 16 17 18 19	I/O	**Bi-Directional Three-State Data Bus Lines:** The outputs are enabled during a read of the C or P ports.
Ground	20		**Ground.**
V_{CC}	40		**+5V Power Supply.**
LA_0 LA_1	39 38	O	**Line Attribute Codes:** These attribute codes have to be decoded externally by the dot/timing logic to generate the horizontal and vertical line combinations for the graphic displays specified by the character attribute codes.
LTEN	37	O	**Light Enable:** Output signal used to enable the video signal to the CRT. This output is active at the programmed underline cursor position, and at positions specified by attribute codes.
RVV	36	O	**Reverse Video:** Output signal used to indicate the CRT circuitry to reverse the video signal. This output is active at the cursor position if a reverse video block cursor is programmed or at the positions specified by the field attribute codes.
VSP	35	O	**Video Suppression:** Output signal used to blank the video signal to the CRT. This output is active: —during the horizontal and vertical retrace intervals. —at the top and bottom lines of rows if underline is programmed to be number 8 or greater. —when an end of row or end of screen code is detected. —when a DMA underrun occurs. —at regular intervals (1/16 frame frequency for cursor, 1/32 frame frequency for character and field attributes)—to create blinking displays as specified by cursor, character attribute, or field attribute programming.
GPA_1 GPA_0	34 33	O	**General Purpose Attribute Codes:** Outputs which are enabled by the general purpose field attribute codes.
HLGT	32	O	**Highlight:** Output signal used to intensify the display at particular positions on the screen as specified by the character attribute codes or field attribute codes.
IRQ	31	O	**Interrupt Request.**
CCLK	30	I	**Character Clock (from dot/timing logic).**
CC_6 CC_5 CC_4 CC_3 CC_2 CC_1 CC_0	29 28 27 26 25 24 23	O	**Character Codes:** Output from the row buffers used for character selection in the character generator.
CS	22	I	**Chip Select:** The read and write are enabled by CS.
A_0	21	I	**Port Address:** A high input on A_0 selects the "C" port or command registers and a low input selects the "P" port or parameter registers.

FUNCTIONAL DESCRIPTION

Data Bus Buffer

This 3-state, bidirectional, 8-bit buffer is used to interface the 8275 to the system Data Bus.

This functional block accepts inputs from the System Control Bus and generates control signals for overall device operation. It contains the Command, Parameter, and Status Registers that store the various control formats for the device functional definition.

A_0	OPERATION	REGISTER
0	Read	PREG
0	Write	PREG
1	Read	SREG
1	Write	CREG

A_0	$\overline{RD}$	$\overline{WR}$	$\overline{CS}$	
0	0	1	0	Write 8275 Parameter
0	1	0	0	Read 8275 Parameter
1	0	1	0	Write 8275 Command
1	1	0	0	Read 8275 Status
X	1	1	0	Three-State
X	X	X	1	Three-state

$\overline{RD}$ (Read)

A "low" on this input informs the 8275 that the CPU is reading data or status information from the 8275.

$\overline{WR}$ (Write)

A "low" on this input informs the 8275 that the CPU is writing data or control words to the 8275.

$\overline{CS}$ (Chip Select)

A "low" on this input selects the 8275. No reading or writing will occur unless the device is selected. When $\overline{CS}$ is high, the Data Bus in the float state and $\overline{RD}$ and $\overline{WR}$ will have no effect on the chip.

DRQ (DMA Request)

A "high" on this output informs the DMA Controller that the 8275 desires a DMA transfer.

$\overline{DACK}$ (DMA Acknowledge)

A "low" on this input informs the 8275 that a DMA cycle is in progress.

IRQ (Interrupt Request)

A "high" on this output informs the CPU that the 8275 desires interrupt service.

FUNCTIONAL DESCRIPTION

Character Counter

The Character Counter is a programmable counter that is used to determine the number of characters to be displayed per row and the length of the horizontal retrace interval. It is driven by the CCLK (Character Clock) input, which should be a derivative of the external dot clock.

Line Counter

The Line Counter is a programmable counter that is used to determine the number of horizontal lines (Sweeps) per character row. Its outputs are used to address the external character generator ROM.

Row Counter

The Row Counter is a programmable counter that is used to determine the number of character rows to be displayed per frame and length of the vertical retrace interval.

Light Pen Registers

The Light Pen Registers are two registers that store the contents of the character counter and the row counter whenever there is a rising edge on the LPEN (Light Pen) input.

Note: Software correction is required.

Raster Timing and Video Controls

The Raster Timing circuitry controls the timing of the HRTC (Horizontal Retrace) and VRTC (Vertical Retrace) outputs. The Video Control circuitry controls the generation of LA_{0-1} (Line Attribute), HGLT (Highlight), RVV (Reverse Video), LTEN (Light Enable), VSP (Video Suppress), and GPA_{0-1} (General Purpose Attribute) outputs.

Row Buffers

The Row Buffers are two 80 character buffers. They are filled from the microcomputer system memory with the character codes to be displayed. While one row buffer is displaying a row of characters, the other is being filled with the next row of characters.

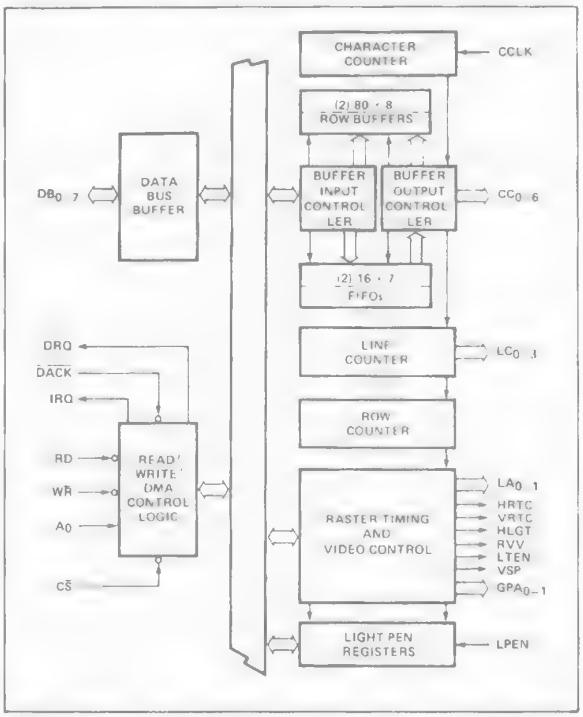


Figure 3. 8275 Block Diagram Showing Counter and Register Functions

FIFOs

There are two 16 character FIFOs in the 8275. They are used to provide extra row buffer length in the Transparent Attribute Mode (see Detailed Operation section).

Buffer Input/Output Controllers

The Buffer Input/Output Controllers decode the characters being placed in the row buffers. If the character is a character attribute, field attribute or special code, these controllers control the appropriate action. (Examples: An "End of Screen–Stop DMA" special code will cause the Buffer Input Controller to stop further DMA requests. A "Highlight" field attribute will cause the Buffer Output Controller to activate the HGLT output.)

SYSTEM OPERATION

The 8275 is programmable to a large number of different display formats. It provides raster timing, display row buffering, visual attribute decoding, cursor timing, and light pen detection.

It is designed to interface with the 8257 DMA Controller and standard character generator ROMs for dot matrix decoding. Dot level timing must be provided by external circuitry.

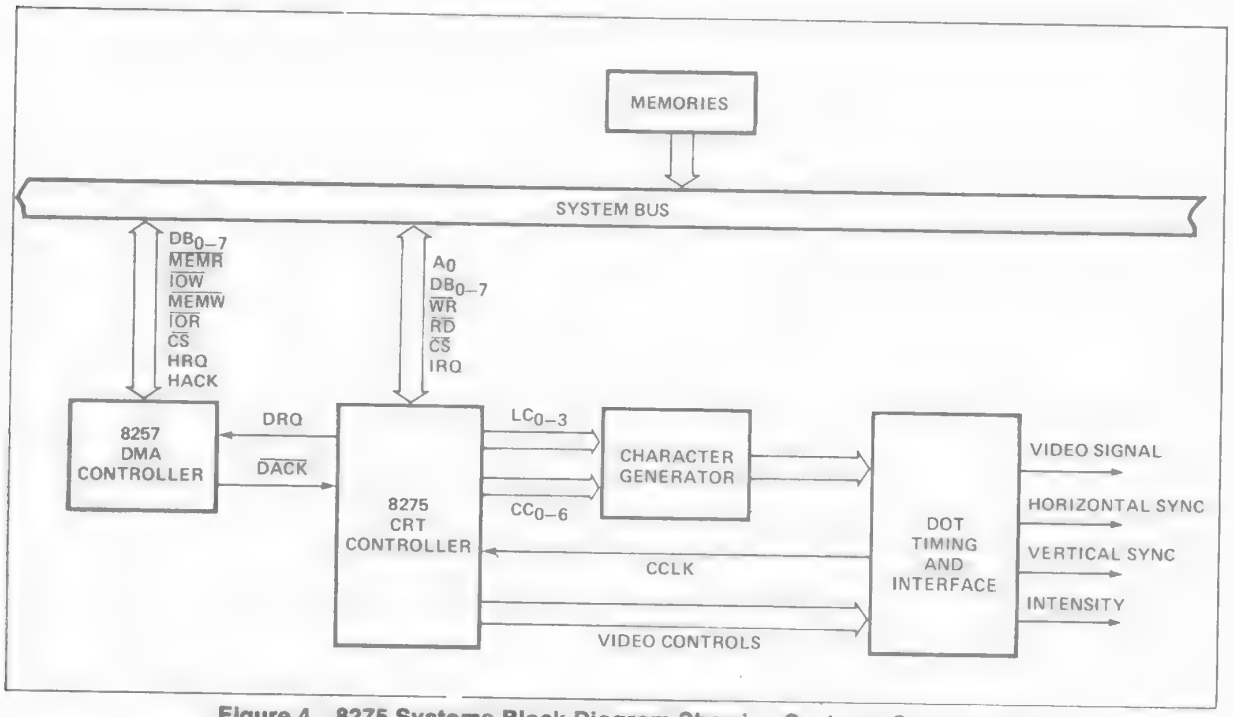


Figure 4. 8275 Systems Block Diagram Showing Systems Operation

AFN-00224B

General Systems Operational Description

The 8275 provides a "window" into the microcomputer system memory.

Display characters are retrieved from memory and displayed on a row by row basis. The 8275 has two row buffers. While one row buffer is being used for display, the other is being filled with the next row of characters to be displayed. The number of display characters per row and the number of character rows per frame are software programmable, providing easy interface to most CRT displays. (See Programming Section.)

The 8275 requests DMA to fill the row buffer that is not being used for display. DMA burst length and spacing is programmable. (See Programming Section.)

The 8275 displays character rows one line at a time.

The number of lines per character row, the underline position, and blanking of top and bottom lines are programmable. (See Programming Section.)

The 8275 provides special Control Codes which can be used to minimize DMA or software overhead. It also provides Visual Attribute Codes to cause special action or symbols on the screen without the use of the character generator (see Visual Attributes Section).

The 8275 also controls raster timing. This is done by generating Horizontal Retrace (HRTC) and Vertical Retrace (VRTC) signals. The timing of these signals is programmable.

The 8275 can generate a cursor. Cursor location and format are programmable. (See Programming Section.)

The 8275 has a light pen input and registers. The light pen input is used to load the registers. Light pen registers can be read on command. (See Programming Section.)

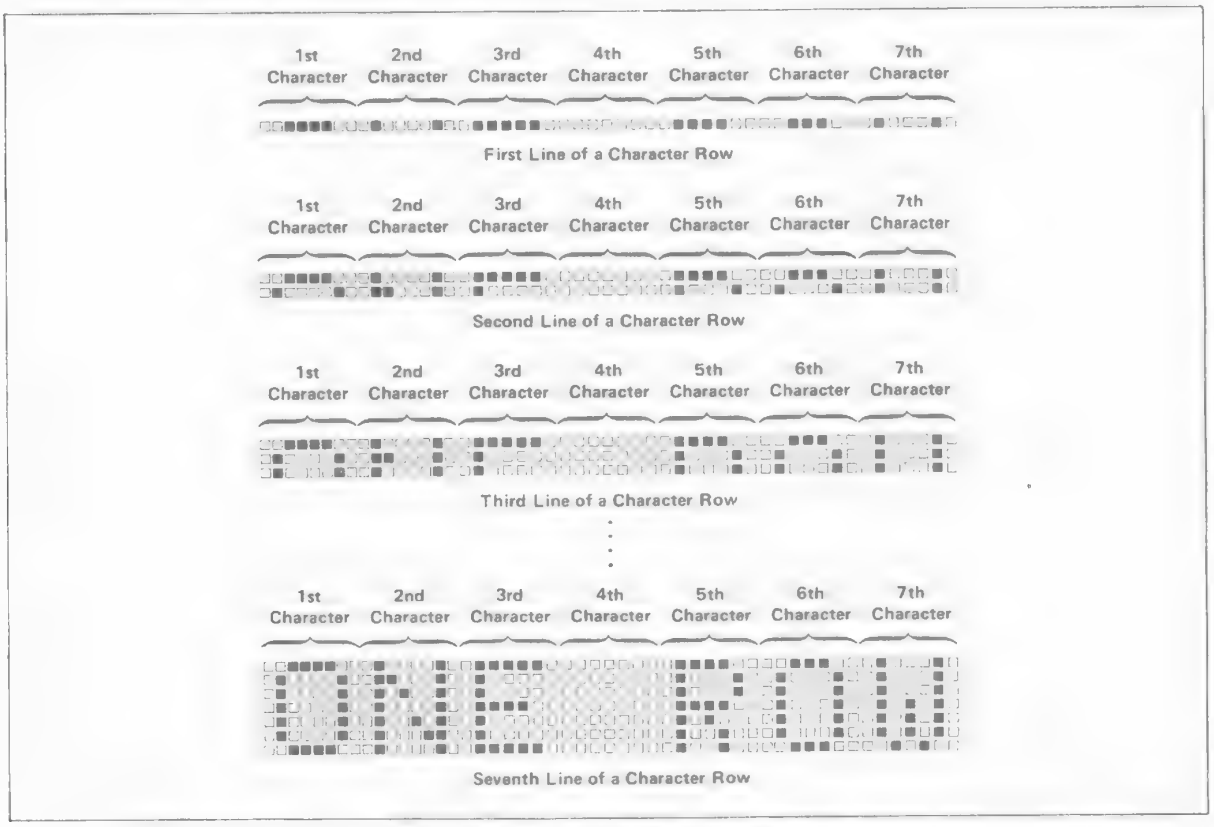


Figure 5. Display of a Character Row

Display Row Buffering

Before the start of a frame, the 8275 requests DMA and one row buffer is filled with characters.

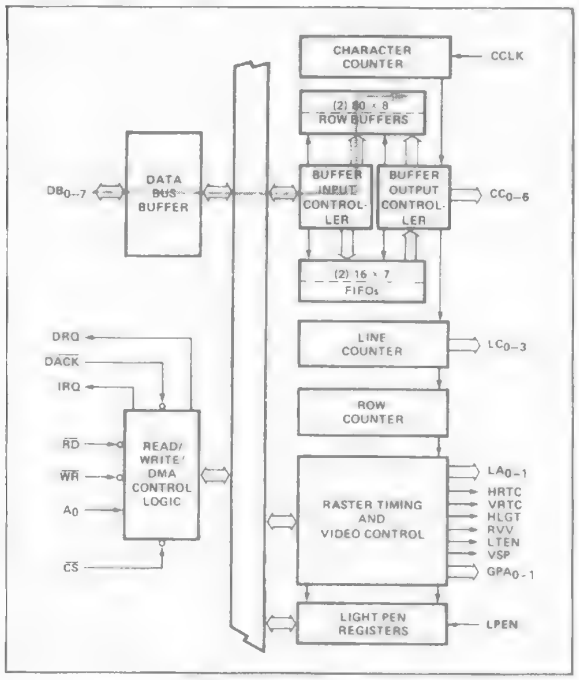


Figure 6. First Row Buffer Filled

When the first horizontal sweep is started, character codes are output to the character generator from the row buffer just filled. Simultaneously, DMA begins filling the other row buffer with the next row of characters.

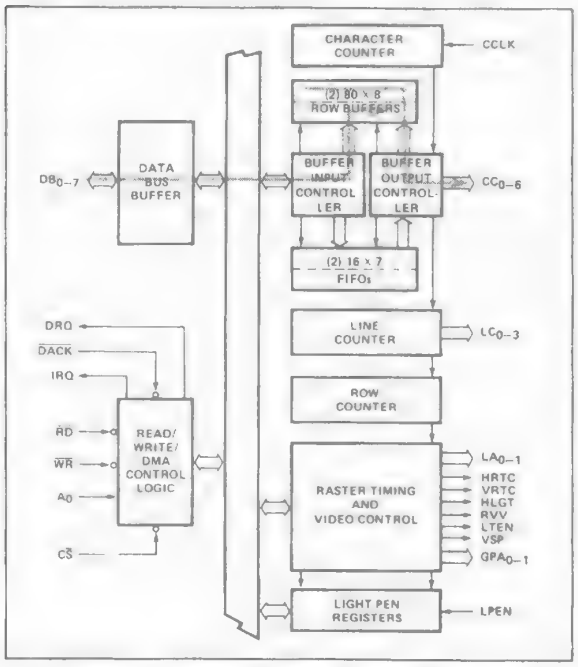


Figure 7. Second Buffer Filled, First Row Displayed

After all the lines of the character row are scanned, the roles of the two row buffers are reversed and the same procedure is followed for the next row.

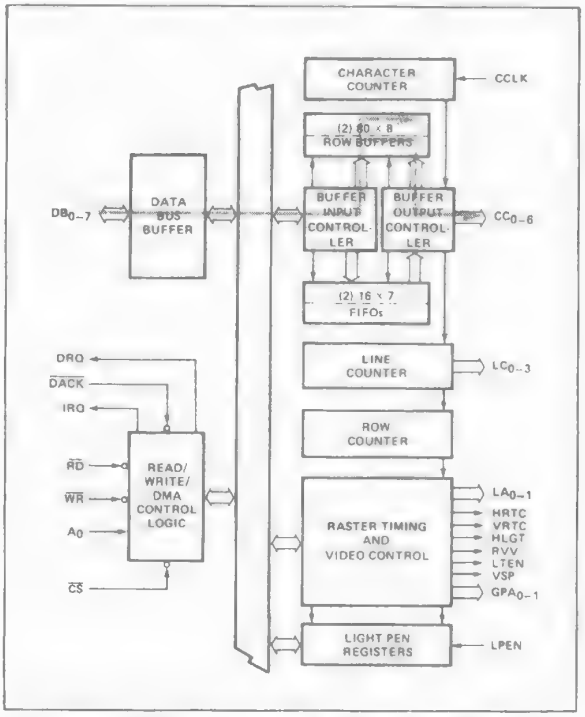


Figure 8. First Buffer Filled with Third Row, Second Row Displayed

This is repeated until all of the character rows are displayed.

Display Format

Screen Format

The 8275 can be programmed to generate from 1 to 80 characters per row, and from 1 to 64 rows per frame.

Figure 9. Screen Format

The 8275 can also be programmed to blank alternate rows. In this mode, the first row is displayed, the second blanked, the third displayed, etc. DMA is not requested for the blanked rows.

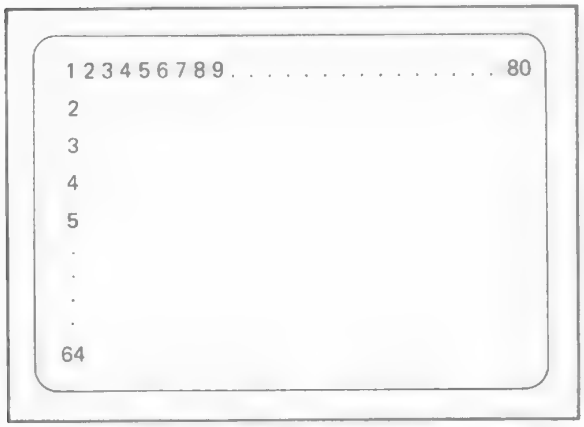


Figure 10. Blank Alternate Rows Mode

Row Format

The 8275 is designed to hold the line count stable while outputting the appropriate character codes during each horizontal sweep. The line count is incremented during horizontal retrace and the whole row of character codes are output again during the next sweep. This is continued until the whole character row is displayed.

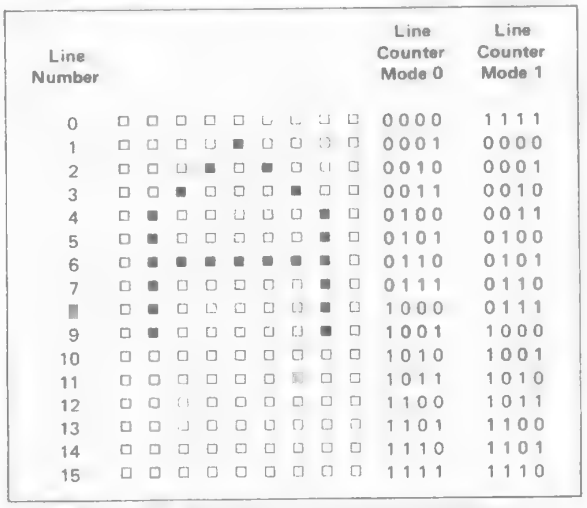
The number of lines (horizontal sweeps) per character row is programmable from 1 to 16.

The output of the line counter can be programmed to be in one of two modes.

In mode 0, the output of the line *counter* is the same as the line *number*.

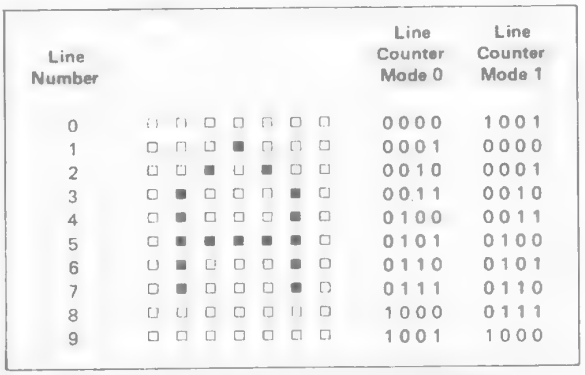
In mode 1, the line *counter* is offset by one from the line *number*.

Note: In mode 1, while the *first* line (line number 0) is being displayed, the *last* count is output by the line counter (see examples).



Line Number	Line Counter Mode 0	Line Counter Mode 1
0	0000	1111
1	0001	0000
2	0010	0001
3	0011	0010
4	0100	0011
5	0101	0100
6	0110	0101
7	0111	0110
8	1000	0111
9	1001	1000
10	1010	1001
11	1011	1010
12	1100	1011
13	1101	1100
14	1110	1101
15	1111	1110

Figure 11. Example of a 16-Line Format



Line Number	Line Counter Mode 0	Line Counter Mode 1
0	0000	1001
1	0001	0000
2	0010	0001
3	0011	0010
4	0100	0011
5	0101	0100
6	0110	0101
7	0111	0110
8	1000	0111
9	1001	1000

Figure 12. Example of a 10-Line Format

Mode 0 is useful for character generators that leave address zero blank and start at address 1. Mode 1 is useful for character generators which start at address zero.

Underline placement is also programmable (from line *number* 0 to 15). This is independent of the line *counter* mode.

If the line *number* of the underline is greater than 7 (line *number* MSB = 1), then the top and bottom lines will be blanked.

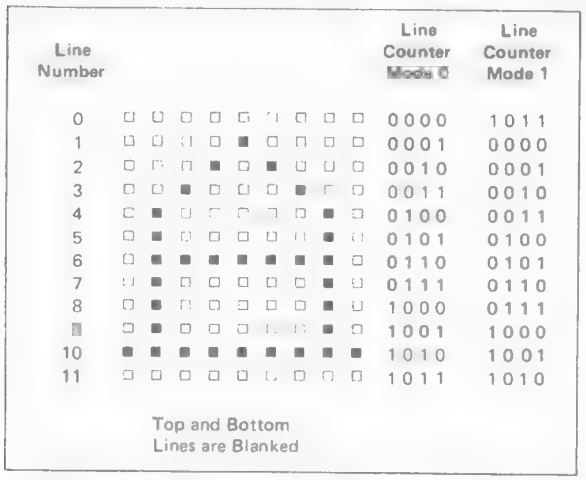


Figure 13. Underline in Line Number 10

If the line *number* of the underline is less than or equal to 7 (line *number* MSB = 0), then the top and bottom lines will *not* be blanked.

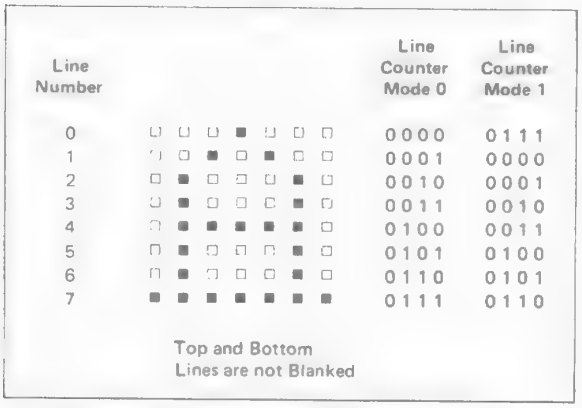


Figure 14. Underline in Line Number 7

If the line *number* of the underline is greater than the maximum number of lines, the underline will not appear.

Blanking is accomplished by the VSP (Video Suppression) signal. Underline is accomplished by the LTEN (Light Enable) signal.

Dot Format

Dot width and character width are dependent upon the external timing and control circuitry.

Dot level timing circuitry should be designed to accept the parallel output of the character generator and shift it out serially at the rate required by the CRT display.

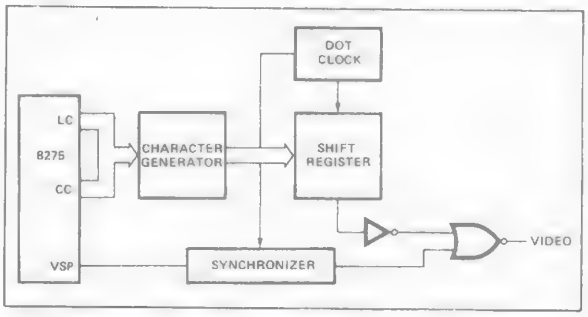


Figure 15. Typical Dot Level Block Diagram

Dot width is a function of dot clock frequency.

Character width is a function of the character generator width.

Horizontal character spacing is a function of the shift register length.

Note: Video control and timing signals must be synchronized with the video signal due to the character generator access delay.

Raster Timing

The character counter is driven by the character clock input (CCLK). It counts out the characters being displayed (programmable from 1 to 80). It then causes the line counter to increment, and it starts counting out the horizontal retrace interval (programmable from 2 to 32). This is constantly repeated.

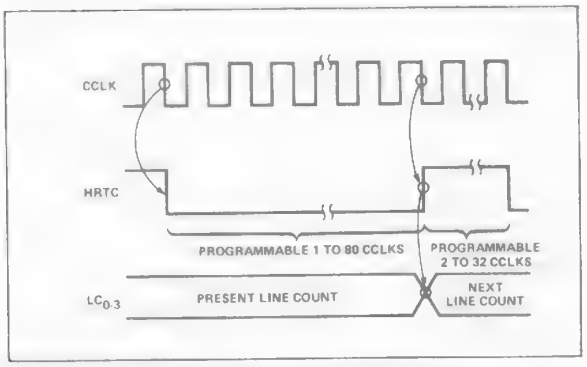


Figure 16. Line Timing

The line counter is driven by the character counter. It is used to generate the line address outputs (LC_{0-3}) for the character generator. After it counts all of the lines in a character row (programmable from 1 to 16), it increments the row counter, and starts over again. (See Character Format Section for detailed description of Line Counter functions.)

The row counter is an internal counter driven by the line counter. It controls the functions of the row buffers and counts the number of character rows displayed.

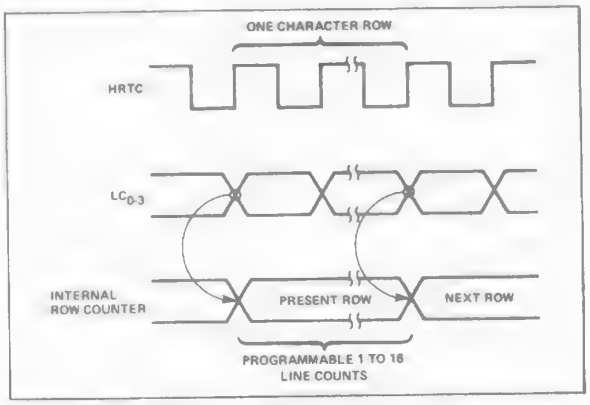


Figure 17. Row Timing

After the row counter counts all of the rows in a frame (programmable from 1 to 64), it starts counting out the vertical retrace interval (programmable from 1 to 4).

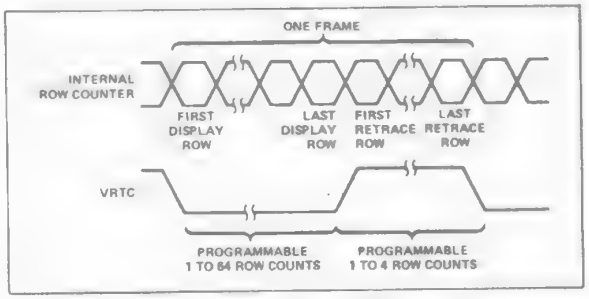


Figure 18. Frame Timing

The Video Suppression Output (VSP) is active during horizontal and vertical retrace intervals.

Dot level timing circuitry must synchronize these outputs with the video signal to the CRT Display.

DMA Timing

The 8275 can be programmed to request burst DMA transfers of 1 to 8 characters. The interval between bursts is also programmable (from 0 to 55 character clock periods ±1). This allows the user to tailor his DMA overhead to fit his system needs.

The first DMA request of the frame occurs one *row time* before the end of vertical retrace. DMA requests continue as programmed, until the row buffer is filled. If the row buffer is filled in the middle of a burst, the 8275 terminates the burst and resets the burst counter. No more DMA requests will occur until the *beginning* of the *next* row. At that time, DMA requests are activated as programmed until the other buffer is filled.

The first DMA request for a row will start at the first character clock of the preceding row. If the burst mode is used the first DMA request may occur a number of character clocks later. This number is equal to the programmed burst space.

If, for any reason, there is a DMA underrun, a flag in the status word will be set.

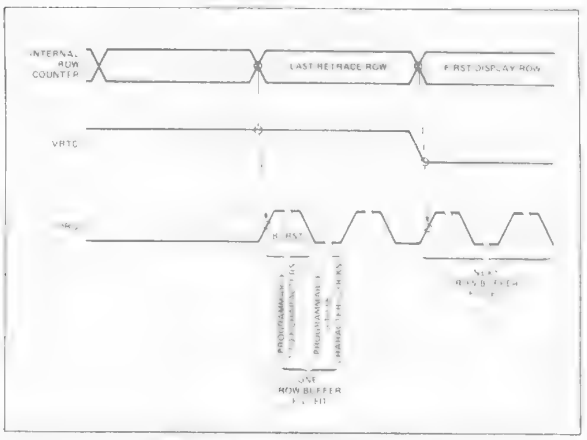


Figure 19. DMA Timing

The DMA controller is typically initialized for the next frame at the end of the current frame.

Interrupt Timing

The 8275 can be programmed to generate an interrupt request at the end of each frame. This can be used to reinitialize the DMA controller. If the 8275 interrupt enable flag is set, an interrupt request will occur at the *beginning* of the *last display row*.

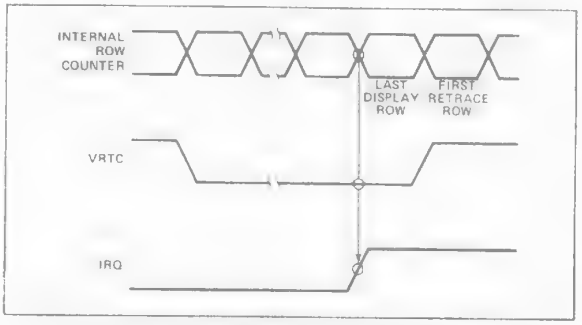


Figure 20. Beginning of Interrupt Request

IRQ will go inactive after the status register is read.

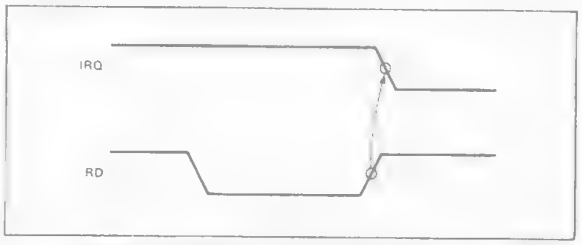


Figure 21. End of Interrupt Request

A reset command will also cause IRQ to go inactive, but this is not recommended during normal service.

Another method of reinitializing the DMA controller is to have the DMA controller itself interrupt on terminal count. With this method, the 8275 interrupt enable flag should not be set.

Note: Upon power-up, the 8275 Interrupt Enable Flag may be set. As a result, the user's cold start routine should write a reset command to the 8275 before system interrupts are enabled.

VISUAL ATTRIBUTES AND SPECIAL CODES

The characters processed by the 8275 are 8-bit quantities. The character code outputs provide the character generator with 7 bits of address. The Most Significant Bit is the extra bit and it is used to determine if it is a normal display character (MSB = 0), or if it is a Visual Attribute or Special Code (MSB = 1).

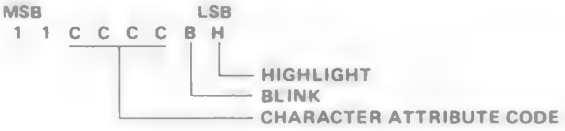
There are two types of Visual Attribute Codes. They are Character Attributes and Field Attributes.

Character Attribute Codes

Character attribute codes are codes that can be used to generate graphics symbols without the use of a character generator. This is accomplished by selectively activating the Line Attribute outputs (LA_{0-1}), the Video Suppression output (VSP), and the Light Enable output. The dot level timing circuitry can use these signals to generate the proper symbols.

Character attributes can be programmed to blink or be highlighted individually. Blinking is accomplished with the Video Suppression output (VSP). Blink frequency is equal to the screen refresh frequency divided by 32. Highlighting is accomplished by activating the Highlight output (HGLT).

Character Attributes



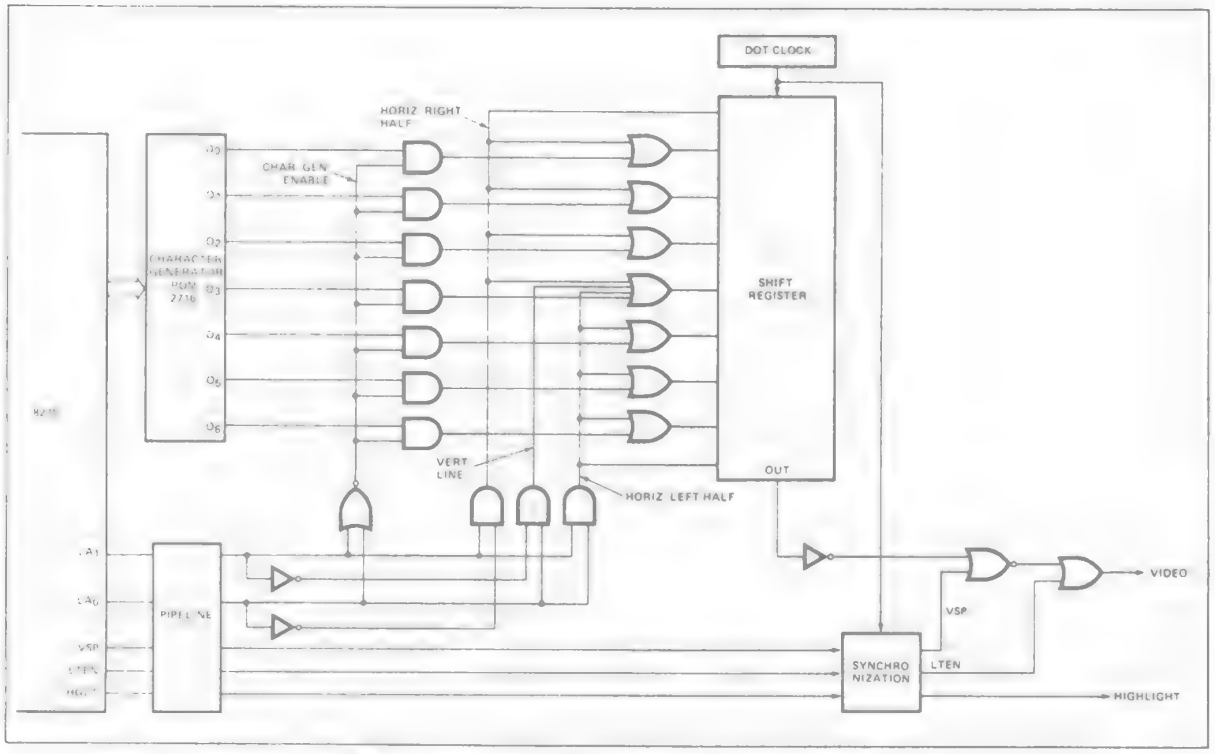
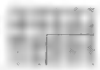
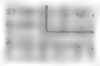
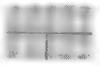
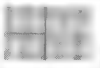
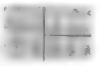
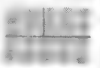
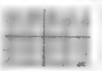


Figure 22. Typical Character Attribute Logic

AFN-00224B

Table 2. Character Attributes

Character attributes were designed to produce the following graphics:

CHARACTER ATTRIBUTE CODE "CCCC"		OUTPUTS				SYMBOL	DESCRIPTION
		LA_1	LA_0	VSP	LTEN		
0000	Above Underline	0	0	1	0		Top Left Corner
	Underline	1	0	0	0		
	Below Underline	0	1	0	0		
0001	Above Underline	0	0	1	0		Top Right Corner
	Underline	1	1	0	0		
	Below Underline	0	1	0	0		
0010	Above Underline	0	1	0	0		Bottom Left Corner
	Underline	1	0	0	0		
	Below Underline	0	0	1	0		
0011	Above Underline	0	1	0	0		Bottom Right Corner
	Underline	1	1	0	0		
	Below Underline	0	0	1	0		
0100	Above Underline	0	0	1	0		Top Intersect
	Underline	0	0	0	1		
	Below Underline	0	1	0	0		
0101	Above Underline	0	1	0	0		Right Intersect
	Underline	1	1	0	0		
	Below Underline	0	1	0	0		
0110	Above Underline	0	1	0	0		Left Intersect
	Underline	1	0	0	0		
	Below Underline	0	1	0	0		
0111	Above Underline	0	1	0	0		Bottom Intersect
	Underline	0	0	0	1		
	Below Underline	0	0	1	0		
1000	Above Underline	0	0	1	0		Horizontal Line
	Underline	0	0	0	1		
	Below Underline	0	0	1	0		
1001	Above Underline	0	1	0	0		Vertical Line
	Underline	0	1	0	0		
	Below Underline	0	1	0	0		
1010	Above Underline	0	1	0	0		Crossed Lines
	Underline	0	0	0	1		
	Below Underline	0	1	0	0		
1011	Above Underline	0	0	0	0		Not Recommended *
	Underline	0	0	0	0		
	Below Underline	0	0	0	0		
1100	Above Underline	0	0	1	0		Special Codes
	Underline	0	0	1	0		
	Below Underline	0	0	1	0		
1101	Above Underline						Illegal
	Underline		Undefined				
	Below Underline						
1110	Above Underline						Illegal
	Underline		Undefined				
	Below Underline						
1111	Above Underline						Illegal
	Underline		Undefined				
	Below Underline						

*Character Attribute Code 1011 is not recommended for normal operation. Since none of the attribute outputs are active, the character Generator will not be disabled, and an indeterminate character will be generated.

Character Attribute Codes 1101, 1110, and 1111 are illegal.

Blinking is active when B = 1.

Highlight is active when H = 1.

Special Codes

Four special codes are available to help reduce memory, software, or DMA overhead.

Special Control Character

S S	FUNCTION
0 0	End of Row
0 1	End of Row-Stop DMA
1 0	End of Screen
1 1	End of Screen-Stop DMA

The End of Row Code (00) activates VSP and holds it to the end of the line.

The End of Row-Stop DMA Code (01) causes the DMA Control Logic to stop DMA for the rest of the row when it is written into the Row Buffer. It affects the display in the same way as the End of Row Code (00).

The End of Screen Code (10) activates VSP and holds it to the end of the frame.

The End of Screen-Stop DMA Code (11) causes the DMA Control Logic to stop DMA for the rest of the frame when it is written into the Row Buffer. It affects the display in the same way as the End of Screen Code (10).

If the Stop DMA feature is not used, all characters after an End of Row character are ignored, except for the End of Screen character, which operates normally. All characters after an End of Screen character are ignored.

Note: If a Stop DMA character is not the last character in a burst or row, DMA is not stopped until after the next character is read. In this situation, a dummy character must be placed in memory after the Stop DMA character.

Field Attributes

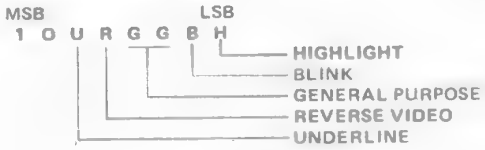
The field attributes are control codes which affect the visual characteristics for a field of characters, starting at the character following the code up to, and including, the character which precedes the *next* field attribute code, or up to the end of the frame. The field attributes are reset during the vertical retrace interval.

There are six field attributes:

1. *Blink* – Characters following the code are caused to blink by activating the Video Suppression output (VSP). The blink frequency is equal to the screen refresh frequency divided by 32.
2. *Highlight* – Characters following the code are caused to be highlighted by activating the Highlight output (HGLT).
3. *Reverse Video* – Characters following the code are caused to appear with reverse video by activating the Reverse Video output (RVV).
4. *Underline* – Characters following the code are caused to be underlined by activating the Light Enable output (LTEN).

5,6. *General Purpose* – There are two additional 8275 outputs which act as general purpose, independently programmable field attributes. GPA_{0-1} are active high outputs.

Field Attribute Code



H = 1 FOR HIGHLIGHTING
B = 1 FOR BLINKING
R = 1 FOR REVERSE VIDEO
U = 1 FOR UNDERLINE
GG = GPA_1, GPA_0

*More than one attribute can be enabled at the same time. If the blinking and reverse video attributes are enabled simultaneously, only the reversed characters will blink.

The 8275 can be programmed to provide visible or invisible field attribute characters.

If the 8275 is programmed in the visible field attribute mode, all field attributes will occupy a position on the screen. They will appear as blanks caused by activation of the Video Suppression output (VSP). The chosen visual attributes are activated after this blanked character.

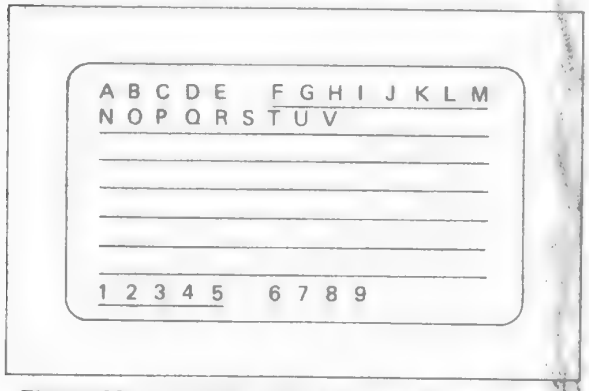


Figure 23. Example of the Visible Field Attribute Mode (Underline Attribute)

If the 8275 is programmed in the invisible field attribute mode, the 8275 FIFO is activated.

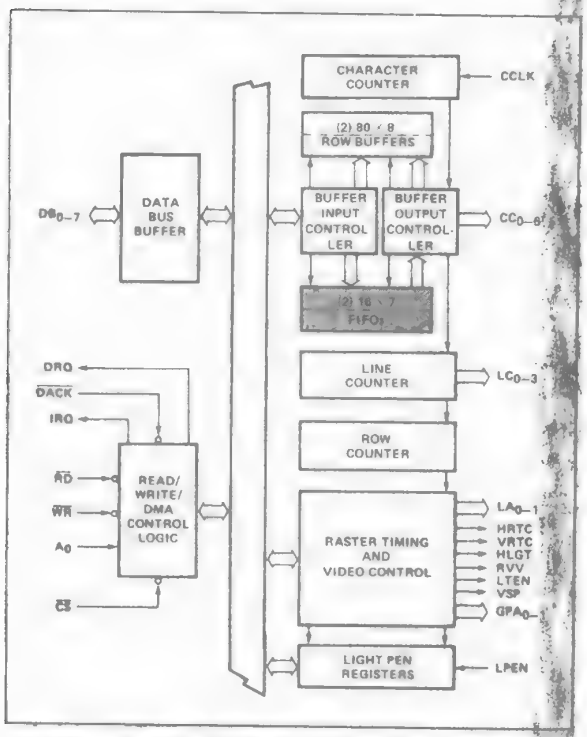


Figure 24. Block Diagram Showing FIFO Activation

Each row buffer has a corresponding FIFO. These FIFOs are 16 characters by 7 bits in size.

When a field attribute is placed in the row buffer during DMA, the buffer input controller recognizes it and places the *next* character in the proper FIFO.

When a field attribute is placed in the Buffer Output Controller during display, it causes the controller to immediately put a character from the FIFO on the Character Code outputs (CC_{0-6}). The chosen Visual Attributes are also activated.

Since the FIFO is 16 characters long, no more than 16 field attribute characters may be used per line in this mode. If more are used, a bit in the status word is set and the first characters in the FIFO are written over and lost.

Note: Since the FIFO is 7 bits wide, the MSB of any characters put in it are stripped off. Therefore, a Visual Attribute or Special Code must *not* immediately follow a field attribute code. If this situation does occur, the Visual Attribute or Special Code will be treated as a normal display character.

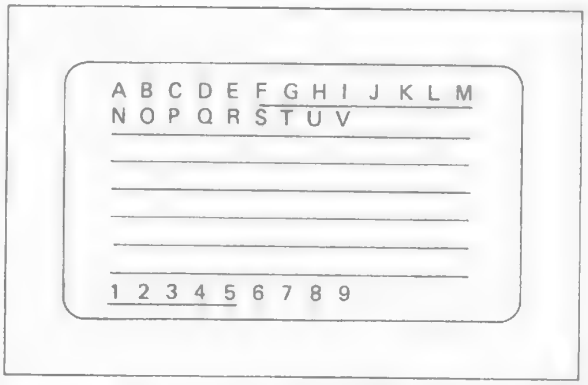


Figure 25. Example of the Invisible Field Attribute Mode (Underline Attribute)

Field and Character Attribute Interaction

Character Attribute Symbols are affected by the Reverse Video (RVV) and General Purpose (GPA_{0-1}) field attributes. They are not affected by Underline, Blink or Highlight field attributes; however, these characteristics can be programmed *individually* for Character Attribute Symbols.

Cursor Timing

The cursor location is determined by a cursor row register and a character position register which are loaded by command to the controller. The cursor can be programmed to appear on the display as:

1. a blinking underline
2. a blinking reverse video block
3. a non-blinking underline
4. a non-blinking reverse video block

The cursor blinking frequency is equal to the screen refresh frequency divided by 16.

If a non-blinking reverse video *cursor* appears in a non-blinking reverse video *field*, the cursor will appear as a normal video block.

If a non-blinking underline *cursor* appears in a non-blinking underline *field*, the cursor will not be visible.

Light Pen Detection

A light pen consists of a micro switch and a tiny light sensor. When the light pen is pressed against the CRT screen, the micro switch enables the light sensor. When the raster sweep reaches the light sensor, it triggers the light pen output.

If the output of the light pen is presented to the 8275 LPEN input, the row and character position coordinates are stored in a pair of registers. These registers can be read on command. A bit in the status word is set, indicating that the light pen signal was detected. The LPEN input must be a 0 to 1 transition for proper operation.

Note: Due to internal and external delays, the character position coordinate will be off by at least three character positions. This has to be corrected in software.

Device Programming

The 8275 has two programming registers, the Command Register (CREG) and the Parameter Register (PREG). It also has a Status Register (SREG). The Command Register can only be written into and the Status Registers can only be read from. They are addressed as follows:

A_0	OPERATION	REGISTER
0	Read	PREG
0	Write	PREG
1	Read	SREG
1	Write	CREG

The 8275 expects to receive a command and a sequence of 0 to 4 parameters, depending on the command. If the proper number of parameter bytes are not received before another command is given, a status flag is set, indicating an improper command.

INSTRUCTION SET

The 8275 instruction set consists of 8 commands.

COMMAND	NO. OF PARAMETER BYTES
Reset	4
Start Display	0
Stop Display	0
Read Light Pen	2
Load Cursor	2
Enable Interrupt	0
Disable Interrupt	0
Preset Counters	0

In addition, the status of the 8275 (SREG) can be read by the CPU at any time.

1. Reset Command:

	OPERATION	A_0	DESCRIPTION	DATA BUS MSB							LSB
Command	Write	1	Reset Command	0	0	0	0	0	0	0	0
Parameters	Write	0	Screen Comp Byte 1	S	H	H	H	H	H	H	H
	Write	0	Screen Comp Byte 2	V	V	R	R	R	R	R	R
	Write	0	Screen Comp Byte 3	U	U	U	U	L	L	L	L
	Write	0	Screen Comp Byte 4	M	F	C	C	Z	Z	Z	Z

Action — After the reset command is written, DMA requests stop, 8275 interrupts are disabled, and the VSP output is used to blank the screen. HRTC and VRTC continue to run. HRTC and VRTC timing are random on power-up.

As parameters are written, the screen composition is defined.

Parameter — S Spaced Rows

S	FUNCTIONS
0	Normal Rows
1	Spaced Rows

Parameter — HHHHHHH Horizontal Characters/Row

H H H H H H H	NO. OF CHARACTERS PER ROW
0 0 0 0 0 0 0	1
0 0 0 0 0 0 1	2
0 0 0 0 0 1 0	3
.	.
.	.
.	.
1 0 0 1 1 1 1	80
1 0 1 0 0 0 0	Undefined
.	.
.	.
.	.
1 1 1 1 1 1 1	Undefined

Parameter — VV Vertical Retrace Row Count

V V	NO. OF ROW COUNTS PER VRTC
0 0	1
0 1	2
1 0	3
1 1	4

Parameter — RRRRRR Vertical Rows/Frame

R R R R R R	NO. OF ROWS/FRAME
0 0 0 0 0 0	1
0 0 0 0 0 1	2
0 0 0 0 1 0	3
.	.
.	.
.	.
1 1 1 1 1 1	64

Parameter — UUUU Underline Placement

U U U U	LINE NUMBER OF UNDERLINE
0 0 0 0	1
0 0 0 1	2
0 0 1 0	3
.	.
.	.
.	.
1 1 1 1	16

Parameter — LLLL Number of Lines per Character Row

L L L L	NO. OF LINES/ROW
0 0 0 0	1
0 0 0 1	2
0 0 1 0	3
.	.
.	.
.	.
1 1 1 1	16

Parameter — M Line Counter Mode

M	LINE COUNTER MODE
0	Mode 0 (Non-Offset)
1	Mode 1 (Offset by 1 Count)

Parameter — F Field Attribute Mode

F	FIELD ATTRIBUTE MODE
0	Transparent
1	Non-Transparent

Parameter — CC Cursor Format

C C	CURSOR FORMAT
0 0	Blinking reverse video block
0 1	Blinking underline
1 0	Nonblinking reverse video block
1 1	Nonblinking underling

Parameter — ZZZZ Horizontal Retrace Count

Z Z Z Z	NO. OF CHARACTER COUNTS PER HRTC
0 0 0 0	2
0 0 0 1	4
0 0 1 0	6
.	.
.	.
.	.
1 1 1 1	32

Note: uuuu MSB determines blanking of top and bottom lines (1 = blanked, 0 = not blanked).

2. Start Display Command:

	OPERATION	A_0	DESCRIPTION	DATA BUS MSB							LSB
Command	Write	1	Start Display	0	0	1	S	S	S	B	B
No parameters											

S S S BURST SPACE CODE

S S S	NO. OF CHARACTER CLOCKS BETWEEN DMA REQUESTS
0 0 0	0
0 0 1	7
0 1 0	15
0 1 1	23
1 0 0	31
1 0 1	39
1 1 0	47
1 1 1	55

B B BURST COUNT CODE

B B	NO. OF DMA CYCLES PER BURST
0 0	1
0 1	2
1 0	4
1 1	8

Action — 8275 interrupts are enabled, DMA requests begin, video is enabled, Interrupt Enable and Video Enable status flags are set.

3. Stop Display Command:

	OPERATION	A_0	DESCRIPTION	DATA BUS MSB							LSB
Command	Write	1	Stop Display	0	1	0	0	0	0	0	0
No parameters											

Action — Disables video, interrupts remain enabled, HRTC and VRTC continue to run, Video Enable status flag is reset, and the "Start Display" command must be given to re-enable the display.

4. Read Light Pen Command

	OPERATION	A_0	DESCRIPTION	DATA BUS							LSB
Command	Write	1	Read Light Pen	0	1	1	0	0	0	0	0
Parameters	Read	0	Char. Number	(Char. Position in Row)							
	Read	0	Row Number	(Row Number)							

Action — The 8275 is conditioned to supply the contents of the light pen position registers in the next two read cycles of the parameter register. Status flags are not affected.

Note: Software correction of light pen position is required.

5. Load Cursor Position:

	OPERATION	A_0	DESCRIPTION	DATA BUS MSB							LSB
Command	Write	1	Load Cursor	1	0	0	0	0	0	0	0
Parameters	Write	0	Char. Number	(Char. Position in Row)							
	Write	0	Row Number	(Row Number)							

Action — The 8275 is conditioned to place the next two parameter bytes into the cursor position registers. Status flags not affected.

6. Enable Interrupt Command:

	OPERATION	A_0	DESCRIPTION	DATA BUS MSB							LSB
Command	Write	1	Enable Interrupt	1	0	1	0	0	0	0	0
No parameters											

Action — The interrupt enable status flag is set and interrupts are enabled.

7. Disable Interrupt Command:

	OPERATION	A_0	DESCRIPTION	DATA BUS MSB							LSB
Command	Write	1	Disable Interrupt	1	1	0	0	0	0	0	0
No parameters											

Action — Interrupts are disabled and the interrupt enable status flag is reset.

8. Preset Counters Command:

	OPERATION	A_0	DESCRIPTION	DATA BUS MSB							LSB
Command	Write	1	Preset Counters	1	1	1	0	0	0	0	0
No parameters											

Action — The internal timing counters are preset, corresponding to a screen display position at the top left corner. Two character clocks are required for this operation. The counters will remain in this state until any other command is given.

This command is useful for system debug and synchronization of clustered CRT displays on a single CPU.

Status Flags

	OPERATION	A_0	DESCRIPTION	DATA BUS MSB LSB
Command	Read	1	Status Word	0 IE IR LP IC VE DU FO

IE — (Interrupt Enable) Set or reset by command. It enables vertical retrace interrupt. It is automatically set by a "Start Display" command and reset with the "Reset" command.

IR — (Interrupt Request) This flag is set at the beginning of display of the last row of the frame if the interrupt enable flag is set. It is reset after a status read operation.

LP — This flag is set when the light pen input (LPEN) is activated and the light pen registers have been loaded. This flag is automatically reset after a status read.

IC — (Improper Command) This flag is set when a command parameter string is too long or too short. The flag is automatically reset after a status read.

VE — (Video Enable) This flag indicates that video operation of the CRT is enabled. This flag is set on a "Start Display" command, and reset on a "Stop Display" or "Reset" command.

DU — (DMA Underrun) This flag is set whenever a data underrun occurs during DMA transfers. Upon detection of DU, the DMA operation is stopped and the screen is blanked until after the vertical retrace interval. This flag is reset after a status read.

FO — (FIFO Overrun) This flag is set whenever the FIFO is overrun. It is reset on a status read.

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias. . . . . 0°C to 70°C
Storage Temperature . . . . . .–65°C to +150°C
Voltage On Any Pin
With Respect to Ground . . . . . –0.5V to +7V
Power Dissipation . . . . . 1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5V ±5%)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
V_{IL}	Input Low Voltage	–0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC}+0.5V	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2.2 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = –400 μA
I_{IL}	Input Load Current		±10	μA	V_{IN} = V_{CC} to 0V
I_{OFL}	Output Float Leakage		±10	μA	V_{OUT} = V_{CC} to 0.45V
I_{CC}	V_{CC} Supply Current		160	mA	

CAPACITANCE (T_A = 25°C, V_{CC} = GND = 0V)

Symbol	Parameter	Min.	Max.	Units	Test Conditions
C_{IN}	Input Capacitance		10	pF	f_c = 1 MHz
$C_{I/O}$	I/O Capacitance		20	pF	Unmeasured pins returned to V_{SS}.

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5.0V ±5%, GND = 0V)

Bus Parameters

READ CYCLE

Symbol	Parameter	Min.	Max.	Units	Test Conditions
t_{AR}	Address Stable Before READ	0		ns	
t_{RA}	Address Hold Time for READ	0		ns	
t_{RR}	READ Pulse Width	250		ns	
t_{RD}	Data Delay from READ		200	ns	C_L = 150 pF
t_{DF}	READ to Data Floating		100	ns	C_L = 150 pF

WRITE CYCLE

Symbol	Parameter	Min.	Max.	Units	Test Conditions
t_{AW}	Address Stable Before WRITE	0		ns	
t_{WA}	Address Hold Time for WRITE	0		ns	
t_{WW}	WRITE Pulse Width	250		ns	
t_{DW}	Data Setup Time for WRITE	150		ns	
t_{WD}	Data Hold Time for WRITE	0		ns	

A.C. CHARACTERISTICS (Continued)

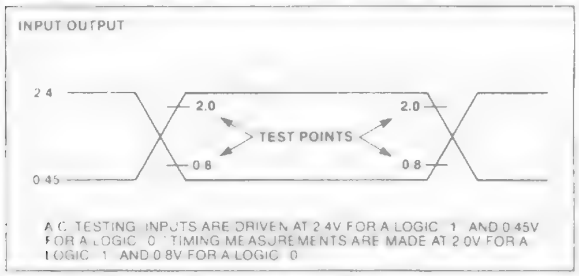
CLOCK TIMING

Symbol	Parameter	8275 Min.	8275 Max.	8275-2 Min.	8275-2 Max.	Units	Test Conditions
t_{CLK}	Clock Period	480		320		ns	
t_{KH}	Clock High	240		120		ns	
t_{KL}	Clock Low	160		120		ns	
t_{KR}	Clock Rise	5	30	5	30	ns	
t_{KF}	Clock Fall	5	30	5	30	ns	

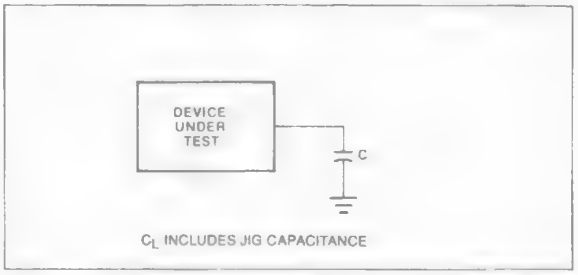
OTHER TIMING

Symbol	Parameter	8275 Min.	8275 Max.	8275-2 Min.	8275-2 Max.	Units	Test Conditions
t_{CC}	Character Code Output Delay		150		150	ns	C_L = 50 pF
t_{HR}	Horizontal Retrace Output Delay		200		150	ns	C_L = 50 pF
t_{LC}	Line Count Output Delay		400		250	ns	C_L = 50 pF
t_{AT}	Control/Attribute Output Delay		275		250	ns	C_L = 50 pF
t_{VR}	Vertical Retrace Output Delay		275		250	ns	C_L = 50 pF
t_{RI}	IRQ↓ from RD↑		250		250	ns	C_L = 50 pF
t_{WQ}	DRQ↑ from WR↑		250		250	ns	C_L = 50 pF
t_{RQ}	DRQ↓ from WR↓		200		200	ns	C_L = 50 pF
t_{LR}	DACK↓ to WR↓	0		0		ns	
t_{RL}	WR↑ to DACK↑	0		0		ns	
t_{PR}	LPEN Rise		50		50	ns	
t_{PH}	LPEN Hold	100		100		ns	

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING LOAD CIRCUIT



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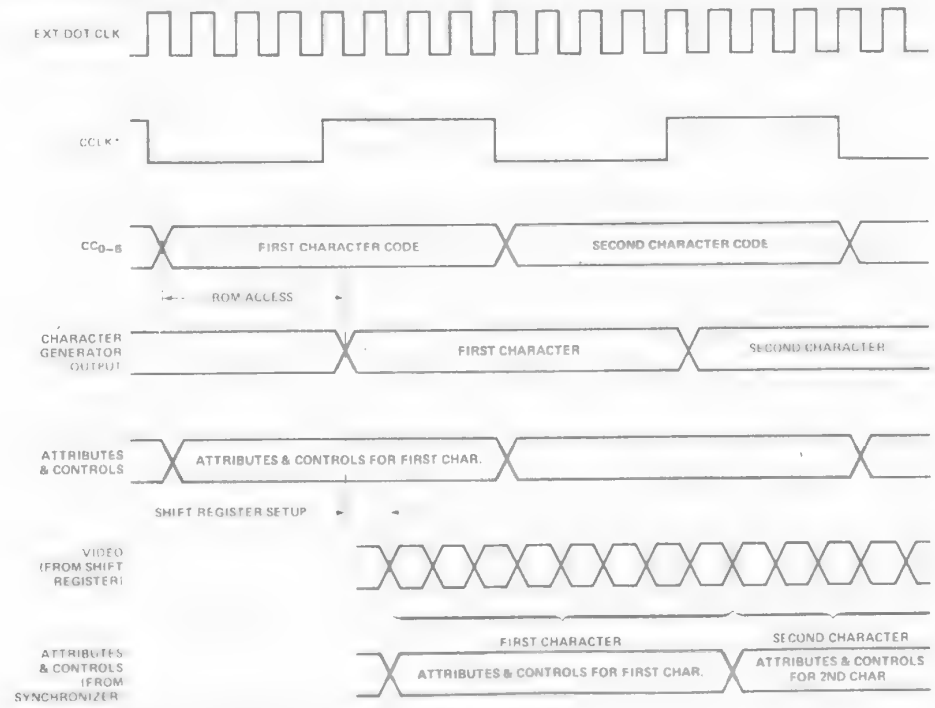
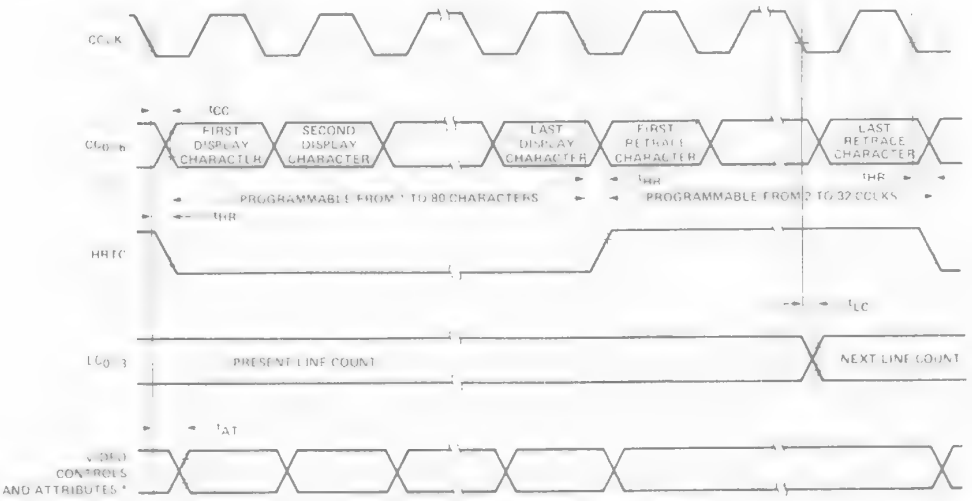
WAVEFORMS

TYPICAL DOT LEVEL TIMING



*CCLK IS A MULTIPLE OF THE DOT CLOCK AND AN INPUT TO THE 8275.

LINE TIMING

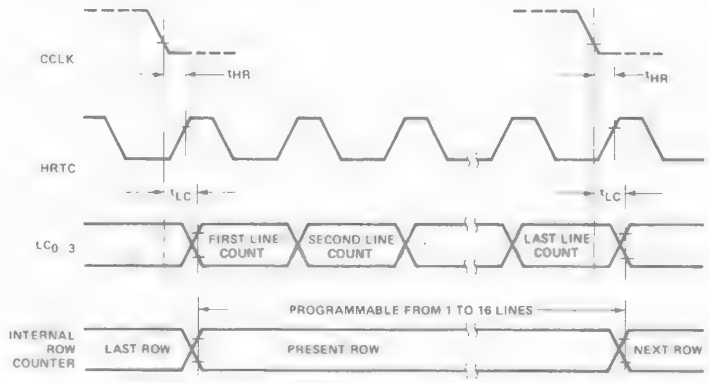


*LA0–1, VSP, LTEN, HGLT, RVV, GPA0–1

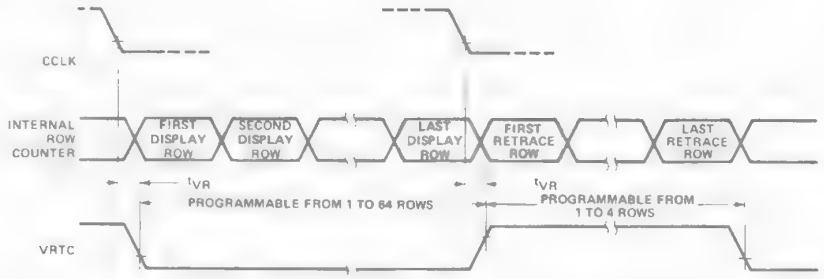
AFN-00224B

WAVEFORMS (Continued)

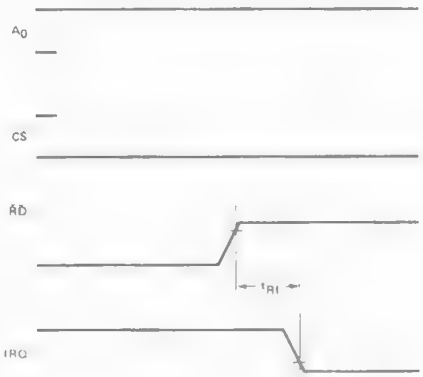
ROW TIMING



FRAME TIMING

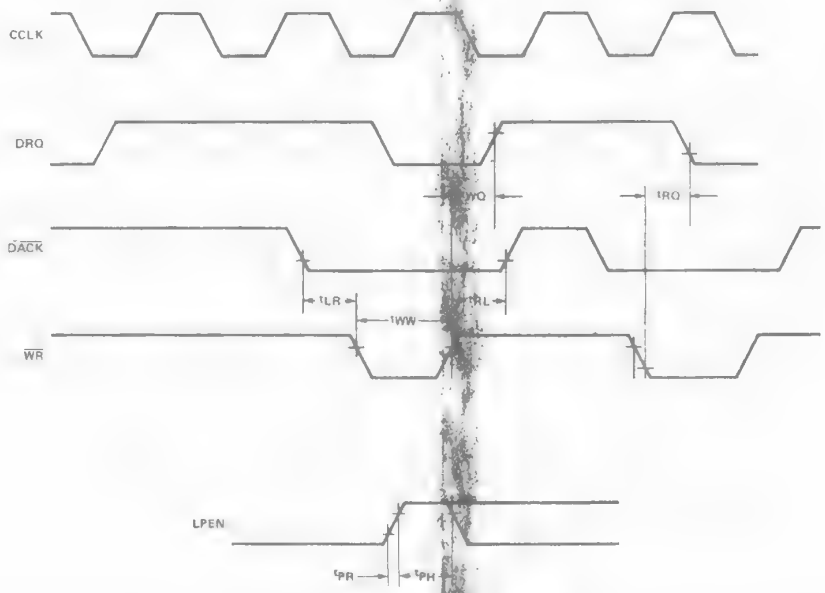


INTERRUPT TIMING

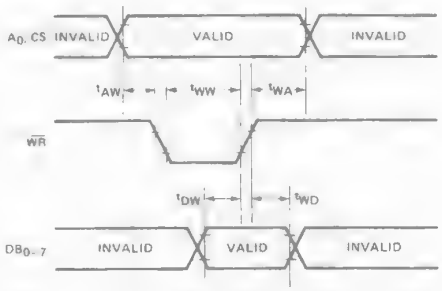


WAVEFORMS (Continued)

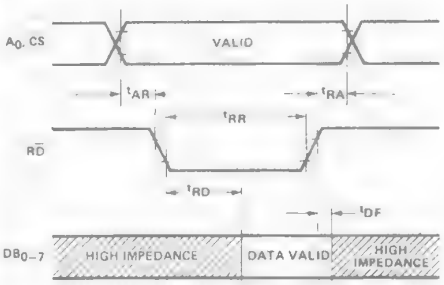
DMA TIMING



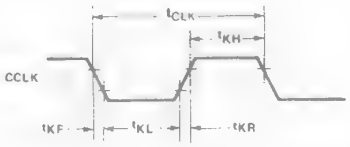
WRITE TIMING



READ TIMING



CLOCK TIMING



AFN-00224C

PRELIMINARY

8276H
SMALL SYSTEM CRT CONTROLLER

- **Programmable Screen and Character Format**
- **6 Independent Visual Field Attributes**
- **Cursor Control (4 Types)**
- **MCS-51®, MCS-85®, iAPX 86, and iAPX 88 Compatible**
- **Dual Row Buffers**
- **Single +5V Supply**
- **40-Pin Package**
- **3 MHz Clock with 8276-2**
- **High Performance HMOS-III**

The Intel 8276H Small System CRT Controller is a single chip device intended to interface CRT raster scan displays with Intel microcomputers in minimum device-count systems. Its primary function is to refresh the display by buffering character information from main memory and keeping track of the display position of the screen. The flexibility designed into the 8276H will allow simple interface to almost any raster scan CRT display. It can be used with the 8051 Single Chip Microcomputer for a minimum IC count design. It is manufactured on Intel's advanced HMOS-II processor.

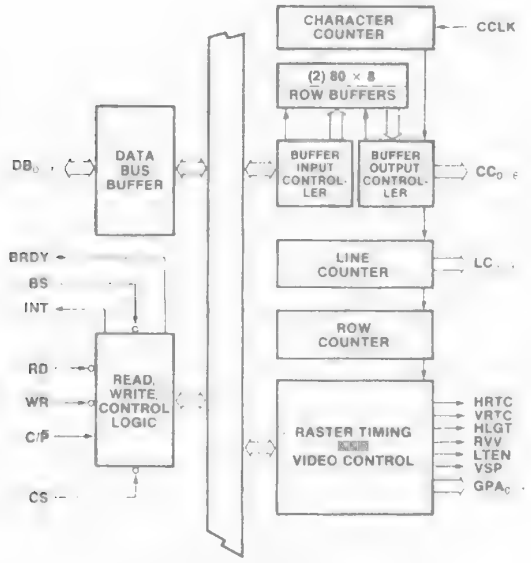


Figure 1. Block Diagram

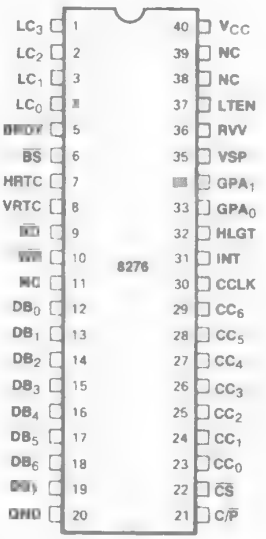


Figure 2. Pin Configuration

Table 1. Pin Descriptions

Symbol	Pin No.	Type	Name and Function
LC_3 LC_2 LC_1 LC_0	1 2 3 4	O	**Line count.** Output from the line counter which is used to address the character generator for the line positions on the screen.
BRDY	5	O	**Buffer ready.** Output signal indicating that a Row Buffer is ready for loading of character data.
$\overline{BS}$	6	I	**Buffer select.** Input signal enabling $\overline{WR}$ for character data into the Row Buffers.
HRTC	7	O	**Horizontal retrace.** Output signal which is active during the programmed horizontal retrace interval. During this period the VSP output is high and the LTEN output is low.
VRTC	8	O	**Vertical retrace.** Output signal which is active during the programmed vertical retrace interval. During this period the VSP output is high and the LTEN output is low.
$\overline{RD}$	9	I	**Read input.** A control signal to read registers.
$\overline{WR}$	10	I	**Write input.** A control signal to write commands into the control registers or write data into the row buffers
NC	11		**No connection.**
DB_0 DB_1 DB_2 DB_3 DB_4 DB_5 DB_6 DB_7	12 13 14 15 16 17 18 19	I/O	**Bidirectional data bus.** Three-state lines. The outputs are enabled during a read of the C or P ports.
Ground	20		**Ground.**
V_{CC}	40		**+5V power supply.**
NC	39		**No connection.**
NC	38		**No connection.**
LTEN	37	O	**Light enable.** Output signal used to enable the video signal to the CRT. This output is active at the programmed underline cursor position, and at positions specified by attribute codes.
RVV	36	O	**Reverse video.** Output signal used to activate the CRT circuitry to reverse the video signal. This output is active at the cursor position if a reverse video block cursor is programmed or at the positions specified by the field attribute codes.
VSP	35	O	**Video suppression.** Output signal used to blank the video signal to the CRT. This output is active: — during the horizontal and vertical retrace intervals. — at the top and bottom lines of rows if underline is programmed to be number 8 or greater. — when an end of row or end of screen code is detected. — when a Row Buffer underrun occurs. — at regular intervals (1/16 frame frequency for cursor, 1/32 frame frequency for attributes)—to create blinking displays as specified by cursor or field attribute programming.
GPA_1 GPA_0	34 33	O	**General purpose attribute codes.**- Outputs which are enabled by the general purpose field attribute codes.
HLGT	32	O	**Highlight.** Output signal used to intensify the display at particular positions on the screen as specified by the field attribute codes.
INT	31	O	**Interrupt output.**
CCLK	30	I	**Character clock** (from dot/timing logic).
CC_6 CC_5 CC_4 CC_3 CC_2 CC_1 CC_0	29 28 27 26 25 24 23	O	**Character codes.** Output from the row buffers used for character selection in the character generator.
$\overline{CS}$	22	I	**Chip select.** Enables $\overline{RD}$ of status or $\overline{WR}$ of command or parameters.
C/ $\overline{P}$	21	I	**Port address.** A high input on this pin selects the "C" port or command registers and a low input selects the "P" port or parameter registers.

AFN-00224B

FUNCTIONAL DESCRIPTION

Data Bus Buffer

This 3-state, bidirectional, 8-bit buffer is used to interface the 8276 to the system Data Bus.

This functional block accepts inputs from the System Control Bus and generates control signals for overall device operation. It contains the Command, Parameter, and Status Registers that store the various control formats for the device functional definition.

C/$\overline{P}$	OPERATION	REGISTER
0	Read	RESERVED
0	Write	PARAMETER
1	Read	STATUS
1	Write	COMMAND

$\overline{RD}$ (READ)
A "low" on this input informs the 8276 that the CPU is reading status information from the 8276.

$\overline{WR}$ (WRITE)
A "low" on this input informs the 8276 that the CPU is writing data or control words to the 8276.

$\overline{CS}$ (CHIP SELECT)
A "low" on this input selects the 8276 for $\overline{RD}$ or $\overline{WR}$ of Commands, Status, and Parameters.

BRDY (BUFFER READY)
A "high" on this output indicates that the 8276 is ready to receive character data.

$\overline{BS}$ (BUFFER SELECT)
A "low" on this input enables $\overline{WR}$ of character data to the 8276 row buffers.

INT (INTERRUPT)
A "high" on this output informs the CPU that the 8276 needs interrupt service.

C/$\overline{P}$	$\overline{RD}$	$\overline{WR}$	$\overline{CS}$	$\overline{BS}$	
0	0	1	0	1	Reserved
0	1	0	0	1	Write 8276 Parameter
1	0	1	0	1	Read 8276 Status
1	1	0	0	1	Write 8276 Command
X	1	0	1	0	Write 8276 Row Buffer
X	1	1	X	X	High Impedance
X	X	X	1	1	High Impedance

Character Counter

The Character Counter is a programmable counter that is used to determine the number of characters to be displayed per row and the length of the horizontal retrace interval. It is driven by the CCLK (Character Clock) input, which should be derived from the external dot clock.

Line Counter

The Line Counter is a programmable counter that is used to determine the number of horizontal lines (Raster Scans) per character row. Its outputs are used to address the external character generator.

Row Counter

The Row Counter is a programmable counter that is used to determine the number of character rows to be displayed per frame and length of the vertical retrace interval.

Raster Timing and Video Controls

The Raster Timing circuitry controls the timing of the HRTC (Horizontal Retrace) and VRTC (Vertical Retrace) outputs. The Video Control circuitry controls the generation of HGLT (Highlight), RVV (Reverse Video), LTEN (Light Enable), VSP (Video Suppress), and GPA_{0-1} (General Purpose Attribute) outputs.

Row Buffers

The Row Buffers are two 80-character buffers. They are filled from the microcomputer system memory with the character codes to be displayed. While one row buffer is displaying a row of characters, the other is being filled with the next row of characters.

Buffer Input/Output Controllers

The Buffer Input/Output Controllers decode the characters being placed in the row buffers. If the character is a field attribute or special code, they control the appropriate action. (Example: A "Highlight" field attribute will cause the Buffer Output Controller to activate the HGLT output.)

SYSTEM OPERATION

The 8276 is programmable to a large number of different display formats. It provides raster timing, display row buffering, visual attribute decoding and cursor timing.

It is designed to interface with standard character generators for dot matrix decoding. Dot level timing must be provided by external circuitry.

General Systems Operational Description

Display characters are retrieved from memory and displayed on a row-by-row basis. The 8276 has two row buffers. While one row buffer is being used for display, the other is being filled with the next row of characters to be displayed. The number of display characters per row and the number of character rows per frame are software programmable, providing easy interface to most CRT displays. (See Programming Section.)

The 8276 uses BRDY to request character data to fill the row buffer that is not being used for display.

The 8276 displays character rows one scan line at a time. The number of scan lines per character row, the underline position, and blanking of top and bottom lines are programmable. (See Programming Section.)

The 8276 provides special Control Codes which can be used to minimize overhead. It also provides Visual Attribute Codes to cause special action on the screen without the use of the character generator. (See Visual Attributes Section.)

The 8276 also controls raster timing. This is done by generating Horizontal Retrace (HRTC) and Vertical Retrace (VRTC) signals. The timing of these signals is also programmable.

The 8276 can generate a cursor. Cursor location and format are programmable. (See Programming Section.)

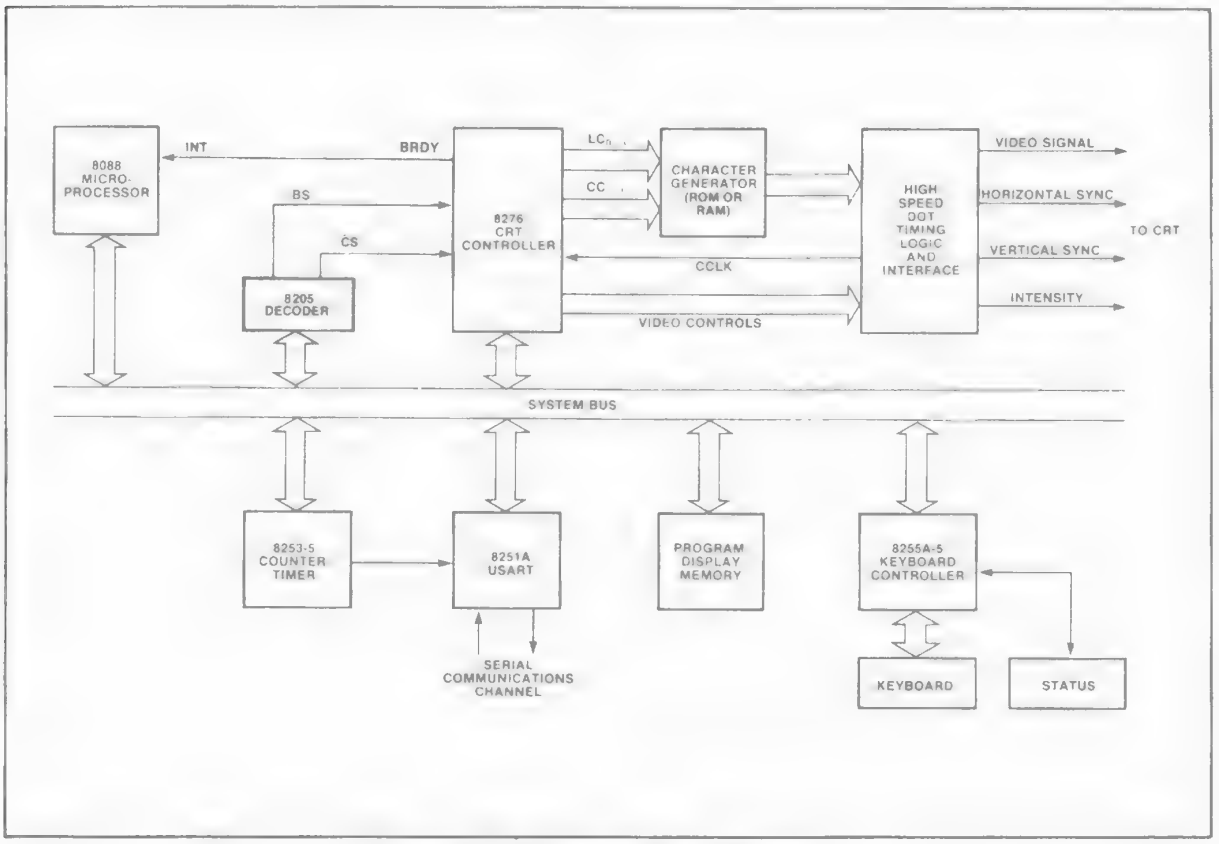


Figure 3. CRT System Block Diagram

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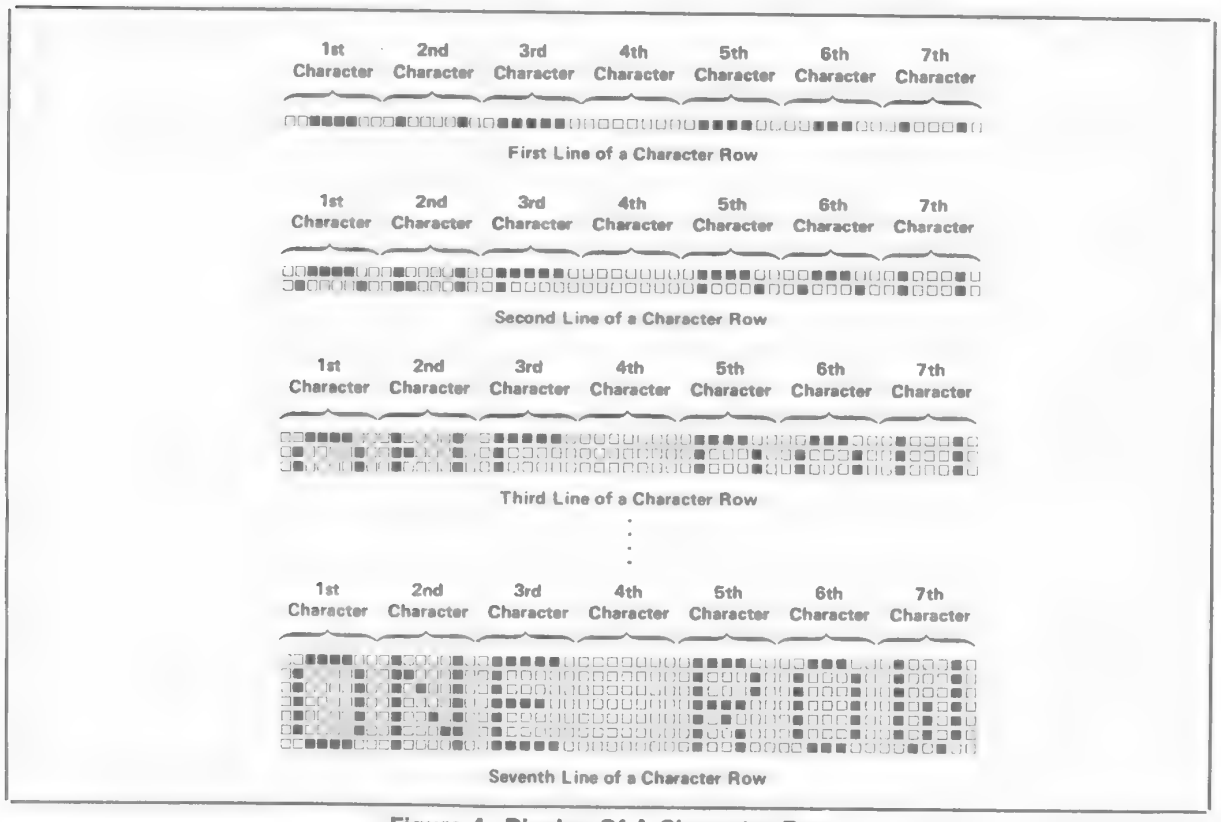

Figure 4. Display Of A Character Row

Display Row Buffering

Before the start of a frame, the 8276 uses BRDY and $\overline{BS}$ to fill one row buffer with characters.

When the first horizontal sweep is started, character codes are output to the character generator from the row buffer just filled. Simultaneously, the other row buffer is filled with the next row of characters.

After all the lines of the character row are scanned, the buffers are swapped and the same procedure is followed for the next row.

This process is repeated until all of the character rows are displayed.

Row Buffering allows the CPU access to the display memory at all times except during Buffer Loading (about 25%). This compares favorably to alternative approaches which restrict CPU access to the display memory to occur only during horizontal and vertical retrace intervals (80% of the bus time is used to refresh the display.)

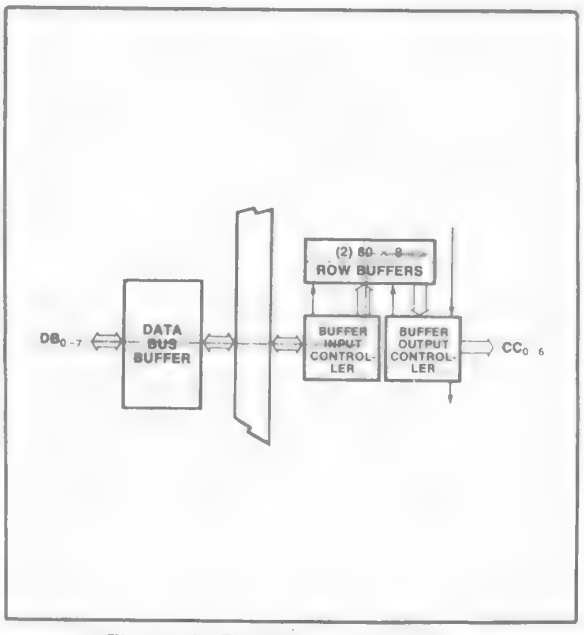

Figure 5. First Row Buffer Filled

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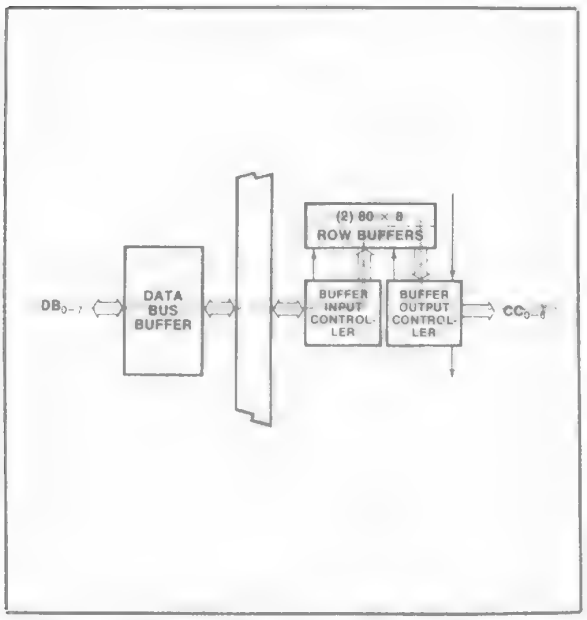


Figure 6. Second Row Buffer Filled, First Row Displayed

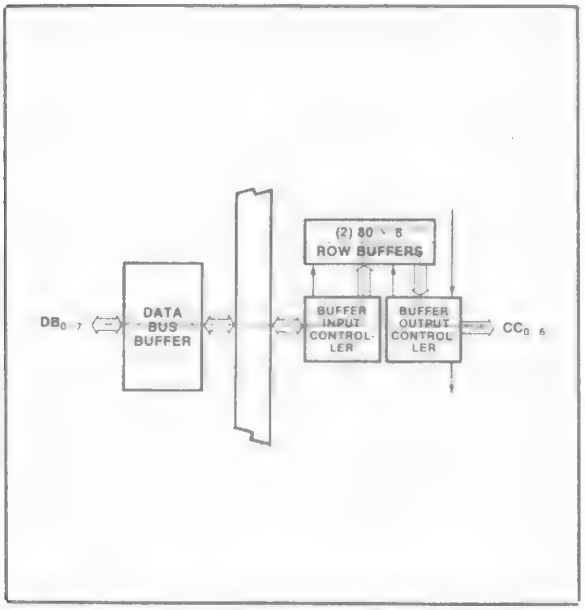


Figure 7. First Row Buffer Filled With Third Row, Second Row Displayed

Display Format

SCREEN FORMAT

The 8276 can be programmed to generate from 1 to 80 characters per row, and from 1 to 64 rows per frame.

Figure 8. Screen Format

The 8276 can also be programmed to blank alternate rows. In this mode, the first row is displayed, the second blanked, the third displayed, etc. Display data is not requested for the blanked rows.

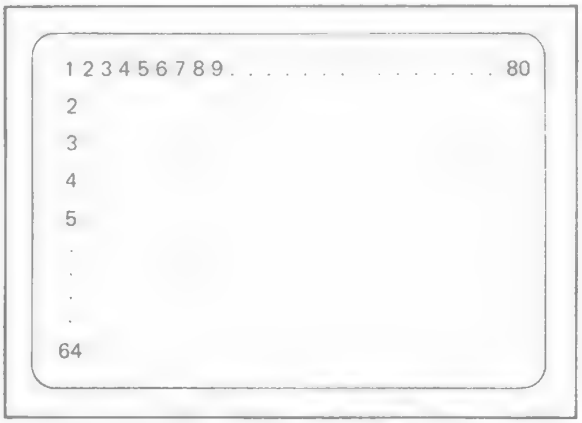


Figure 9. Blank Alternate Rows Mode

ROW FORMAT

The 8276 is designed to hold the line count stable while outputting the appropriate character codes during each horizontal sweep. The line count is incremented during horizontal retrace and the whole row of character codes are output again during the next sweep. This is continued until the entire character row is displayed.

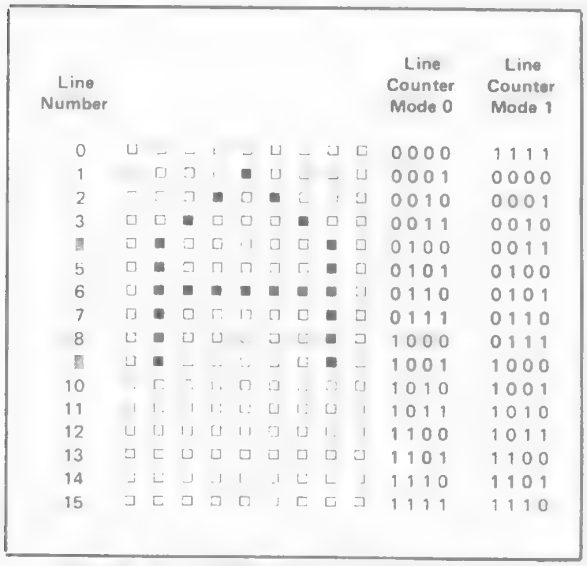
The number of lines (horizontal sweeps) per character row is programmable from 1 to 16.

The output of the line counter can be programmed to be in one of two modes.

In mode 0, the output of the line *counter* is the same as the line *number*.

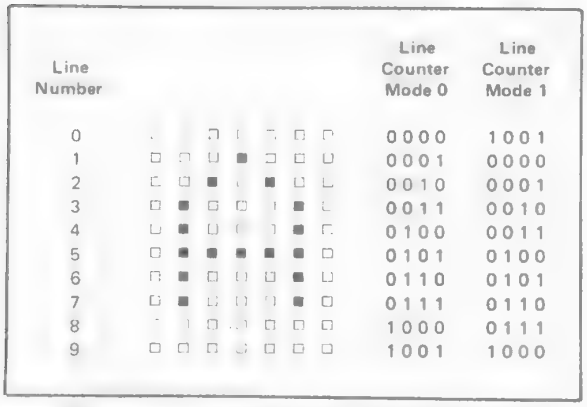
In mode 1, the line *counter* is offset by one from the line *number*.

Note: In mode 1, while the *first* line (line number 0) is being displayed, the *last* count is output by the line counter (see examples).



Line Number	Line Counter Mode 0	Line Counter Mode 1
0	0000	1111
1	0001	0000
2	0010	0001
3	0011	0010
4	0100	0011
5	0101	0100
6	0110	0101
7	0111	0110
8	1000	0111
9	1001	1000
10	1010	1001
11	1011	1010
12	1100	1011
13	1101	1100
14	1110	1101
15	1111	1110

Figure 10. Example of a 16-Line Format



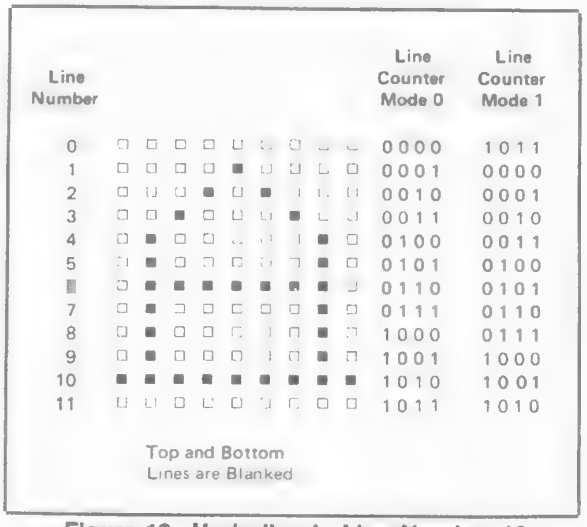
Line Number	Line Counter Mode 0	Line Counter Mode 1
0	0000	1001
1	0001	0000
2	0010	0001
3	0011	0010
4	0100	0011
5	0101	0100
6	0110	0101
7	0111	0110
8	1000	0111
9	1001	1000

Figure 11. Example of a 10-Line Format

Mode 0 is useful for character generators that leave address zero blank and start at address 1. Mode 1 is useful for character generators which start at address zero.

Underline placement is also programmable (from line *number* 0 to 15). This is independent of the line *counter* mode.

If the line *number* of the underline is greater than 7 (line *number* MSB = 1), then the top and bottom lines will be blanked.

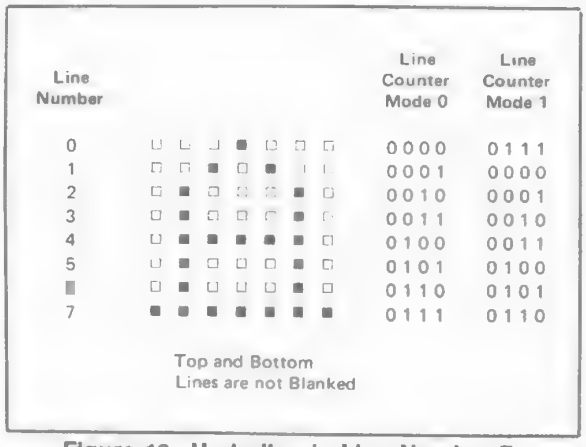


Line Number	Line Counter Mode 0	Line Counter Mode 1
0	0000	1011
1	0001	0000
2	0010	0001
3	0011	0010
4	0100	0011
5	0101	0100
6	0110	0101
7	0111	0110
8	1000	0111
9	1001	1000
10	1010	1001
11	1011	1010

Top and Bottom Lines are Blanked

Figure 12. Underline in Line Number 10

If the line *number* of the underline is less than or equal to 7 (line *number* MSB = 0), then the top and bottom lines will *not* be blanked.



Line Number	Line Counter Mode 0	Line Counter Mode 1
0	0000	0111
1	0001	0000
2	0010	0001
3	0011	0010
4	0100	0011
5	0101	0100
6	0110	0101
7	0111	0110

Top and Bottom Lines are not Blanked

Figure 13. Underline in Line Number 7

If the line *number* of the underline is greater than the maximum number of lines, the underline will not appear.

Blanking is accomplished by the VSP (Video Suppression) signal. Underline is accomplished by the LTEN (Light Enable) signal.

DOT FORMAT

Dot width and character width are dependent upon the external timing and control circuitry.

Dot level timing circuitry should be designed to accept the parallel output of the character generator and shift it out serially at the rate required by the CRT display.

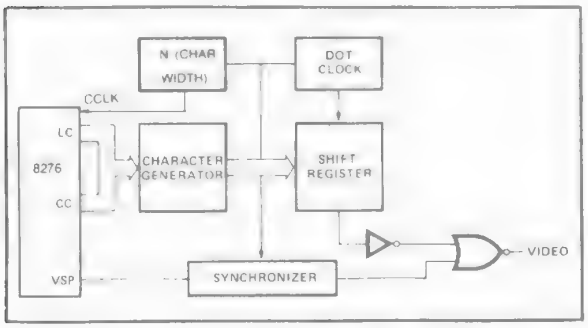


Figure 14. Typical Dot Level Block Diagram

Dot width is a function of dot clock frequency.

Character width is a function of the character generator width.

Horizontal character spacing is a function of the shift register length.

Note: Video control and timing signals must be synchronized with the video signal due to the character generator access delay.

Raster Timing

The character counter is driven by the character clock input (CCLK). It counts out the characters being displayed (programmable from 1 to 80). It then causes the line counter to increment, and it starts counting out the horizontal retrace interval (programmable from 2 to 32). This process is constantly repeated.

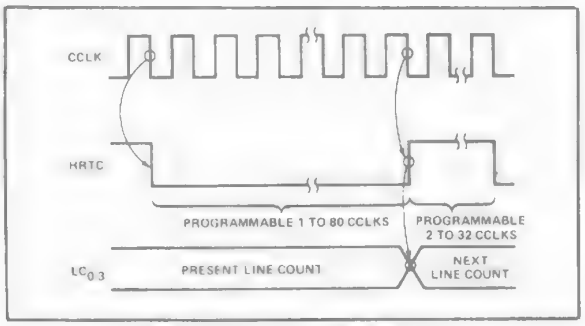


Figure 15. Line Timing

The line counter is driven by the character counter. It is used to generate the line address outputs (LC_{0-3}) for the character generator. After it counts all of the lines in a character row (programmable from 1 to 16), it increments the row counter, and starts over again. (See Character Format Section for detailed description of Line Counter functions.)

The row counter is an internal counter driven by the line counter. It controls the functions of the row buffers and counts the number of character rows displayed.

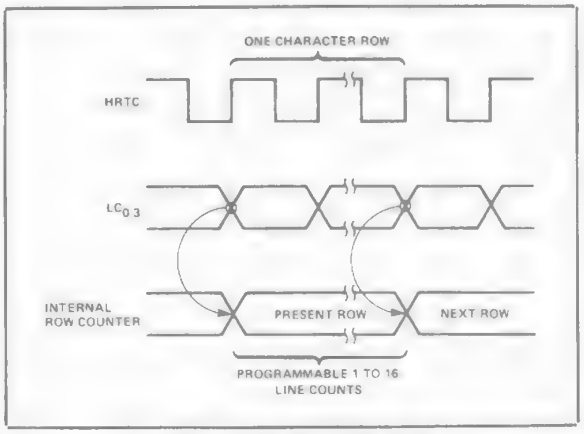


Figure 16. Row Timing

After the row counter counts all of the rows in a frame (programmable from 1 to 64), it starts counting out the vertical retrace interval (programmable from 1 to 4).

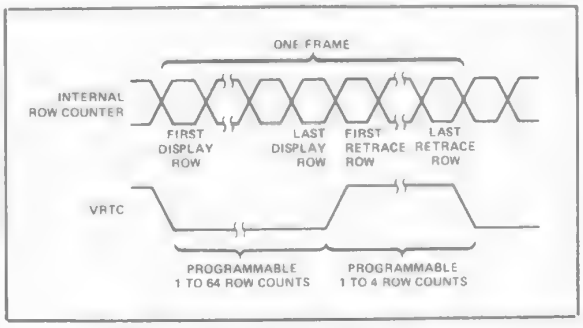


Figure 17. Frame Timing

The Video Suppression Output (VSP) is active during horizontal and vertical retrace intervals.

Dot level timing circuitry must synchronize these outputs with the video signal to the CRT Display.

Interrupt Timing

The 8276 can be programmed to generate an interrupt request at the end of each frame. If the 8276 interrupt enable flag is set, an interrupt request will occur at the *beginning* of the *last display row*.

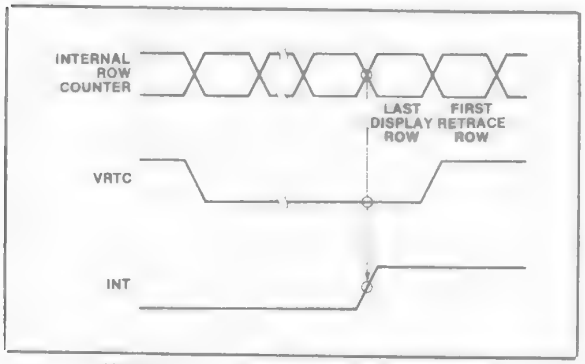


Figure 18. Beginning of Interrupt

INT will go inactive after the status register is read.

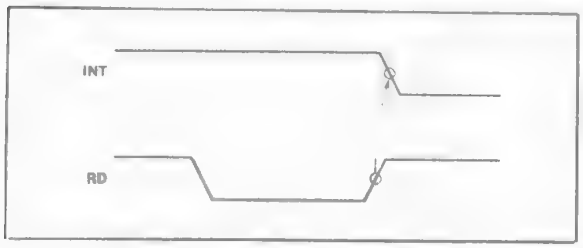


Figure 19. End of Interrupt

A reset command will also cause INT to go inactive, but this is not recommended during normal service.

Note: Upon power-up, the 8276 Interrupt Enable Flag may be set. As a result, the user's cold start routine should write a reset command to the 8276 before system interrupts are enabled.

VISUAL ATTRIBUTES AND SPECIAL CODES

The characters processed by the 8276 are 8-bit quantities. The character code outputs provide the character generator with 7 bits of address. The Most Significant Bit is the extra bit and it is used to determine if it is a normal display character (MSB = 0), or if it is a Field Attribute or Special Code (MSB = 1).

Special Codes

Four special codes are available to help reduce bus usage.

SPECIAL CONTROL CHARACTER

MSB LSB

1 1 1 1 0 0 S S — SPECIAL CONTROL CODE

S	S	FUNCTION
0	0	End of Row
0	1	End of Row-Stop Buffer Loading
1	0	End of Screen
1	1	End of Screen-Stop Buffer Loading

The End of Row Code (00) activates VSP and holds it to the end of the line.

The End of Row-Stop Buffer Loading (BRDY) Code (01) causes the Buffer Loading Control Logic to stop buffer loading for the rest of the row upon being written into the Row Buffer. It affects the display in the same way as the End of Row Code (00).

The End of Screen Code (10) activates VSP and holds it to the end of the frame.

The End of Screen-Stop Buffer Loading (BRDY) Code (11) causes the Row Buffer Control Logic to stop buffer loading for the rest of the frame upon being written. It affects the display in the same way as the End of Screen Code (10).

If the Stop Buffer Loading feature is not used, all characters after an End of Row character are ignored, except for the End of Screen character, which operates normally. All characters after an End of Screen character are ignored.

Note: If a Stop Buffer Loading is not the last character in a row, Buffer Loading is not stopped until after the next character is read. In this situation, a dummy character must be placed in memory after the Stop Buffer Loading character.

Field Attributes

The field attributes are control codes which affect the visual characteristics for a field of characters, starting at the character following the code up to, and including, the character which precedes the *next* field attribute code, or up to the end of the frame. The field attributes are reset during the vertical retrace interval.

The 8276 can be programmed to provide visible field attribute characters; all field attribute codes will occupy a position on the screen. These codes will appear as blanks caused by activation of the Video Suppression output (VSP). The chosen visual attributes are activated after this blanked character.

There are six field attributes:

1. *Blink*—Characters following the code are caused to blink by activating the Video Suppression output (VSP). The blink frequency is equal to the screen refresh frequency divided by 32.
2. *Highlight*—Characters following the code are caused to be highlighted by activating the Highlight output (HGLT).
3. *Reverse Video*—Characters following the code are caused to appear with reverse video by activating the Reverse Video output (RVV).
4. *Underline*—Characters following the code are caused to be underlined by activating the Light Enable output (LTEN).

5,6. *General Purpose*—There are two additional 8276 outputs which act as general purpose, independently programmable field attributes. GPA_{0-1} are active high outputs.

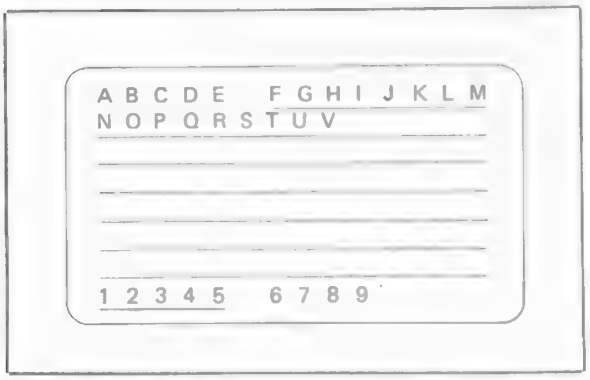
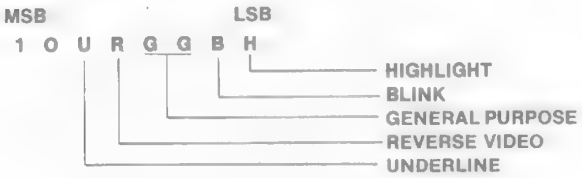


Figure 20. Example of a Visible Field Attribute (Underline Attribute)

FIELD ATTRIBUTE CODE



H = 1 FOR HIGHLIGHTING
B = 1 FOR BLINKING
R = 1 FOR REVERSE VIDEO
U = 1 FOR UNDERLINE
GG = GPA_1, GPA_0

Note: More than one attribute can be enabled at the same time. If the blinking and reverse video attributes are enabled simultaneously, only the reversed characters will blink.

Cursor Timing

The cursor location is determined by a cursor row register and a character position register which are loaded by command to the controller. The cursor can be programmed to appear on the display as:

1. a blinking underline
2. a blinking reverse video block
3. a non-blinking underline
4. a non-blinking reverse video block

The cursor blinking frequency is equal to the screen refresh frequency divided by 16.

If a non-blinking reverse video *cursor* appears in a non-blinking reverse video *field*, the cursor will appear as a normal video block.

If a non-blinking underline *cursor* appears in a non-blinking underline *field*, the cursor will not be visible.

Device Programming

The 8276 has two programming registers, the Command Register and the Parameter Register. It also has a Status Register. The Command Register can only be written into and the Status Register can only be read from. They are addressed as follows:

C/$\overline{P}$	OPERATION	REGISTER
0	Read	Reserved
0	Write	Parameter
1	Read	Status
1	Write	Command

The 8276 expects to receive a command and a sequence of 0 to 4 parameters, depending on the command. If the proper number of parameter bytes are not received before another command is given, a status flag is set, indicating an improper command.

Instruction Set

The 8276 instruction set consists of 7 commands.

COMMAND	NO. OF PARAMETER BYTES
Reset	4
Start Display	0
Stop Display	0
Load Cursor	2
Enable Interrupt	0
Disable Interrupt	0
Preset Counters	0

In addition, the status of the 8276 can be read by the CPU at any time.

1. RESET COMMAND

	OPERATION	C/P	DESCRIPTION	DATA BUS MSB LSB
Command	Write	1	Reset Command	0 0 0 0 0 0 0 0
Parameters	Write	0	Screen Comp Byte 1	S H H H H H H H
	Write	0	Screen Comp Byte 2	V V R R R R R R
	Write	0	Screen Comp Byte 3	U U U U L L L L
	Write	0	Screen Comp Byte 4	M 1 C C Z Z Z Z

Action—After the reset command is written, BRDY goes inactive, 8276 interrupts are disabled, and the VSP output is used to blank the screen. HRTC and VRTC continue to run. HRTC and VRTC timing are random on power-up

As parameters are written, the screen composition is defined.

Parameter—S Spaced Rows

S	FUNCTIONS
0	Normal Rows
1	Spaced Rows

Parameter—HHHHHHH Horizontal Characters/Row

H H H H H H H	NO. OF CHARACTERS PER ROW
0 0 0 0 0 0 0	1
0 0 0 0 0 0 1	2
0 0 0 0 0 1 0	3
.	.
.	.
.	.
1 0 0 1 1 1 1	50
1 0 1 0 0 0 0	Undefined
.	.
.	.
.	.
1 1 1 1 1 1 1	Undefined

Parameter—VV Vertical Retrace Row Count

V V	NO. OF ROW COUNTS PER VRTC
0 0	1
0 1	2
1 0	3
1 1	4

Parameter—RRRRRR Vertical Rows/Frame

R R R R R R	NO. OF ROWS/FRAME
0 0 0 0 0 0	1
0 0 0 0 0 1	2
0 0 0 0 1 0	3
.	.
.	.
.	.
1 1 1 1 1 1	64

Parameter—UUUU Underline Placement

U U U U	LINE NUMBER OF UNDERLINE
0 0 0 0	1
0 0 0 1	2
0 0 1 0	3
.	.
.	.
.	.
1 1 1 1	16

Parameter—LLLL Number of Lines per Character Row

L L L L	NO. OF LINES/ROW
0 0 0 0	1
0 0 0 1	2
0 0 1 0	3
.	.
.	.
.	.
1 1 1 1	16

Parameter—M Line Counter Mode

M	LINE COUNTER MODE
0	Mode 0 (Non-Offset)
1	Mode 1 (Offset by 1 Count)

Parameter—CC Cursor Format

C C	CURSOR FORMAT
0 0	Blinking reverse video block
0 1	Blinking underline
1 0	Non-blinking reverse video block
1 1	Non-blinking underline

Parameter—ZZZZ Horizontal Retrace Count

Z Z Z Z	NO. OF CHARACTER COUNTS PER HRTC
0 0 0 0	2
0 0 0 1	4
0 0 1 0	[illegible]
.	.
.	.
.	.
1 1 1 1	32

Note: uuuu MSB determines blanking of top and bottom lines (1 = blanked, 0 = not blanked).

2. START DISPLAY COMMAND

	OPERATION	C/P	DESCRIPTION	DATA BUS MSB LSB
Command	Write	1	Start Display	0 0 1 0 0 0 0 0
No parameters				

Action—8276 interrupts are enabled, BRDY goes active, video is enabled, Interrupt Enable and Video Enable status flags are set.

3. STOP DISPLAY COMMAND

	OPERATION	C/P	DESCRIPTION	DATA BUS MSB LSB
Command	Write	1	Stop Display	0 1 0 0 0 0 0 0
No parameters				

Action—Disables video, interrupts remain enabled, HRTC and VRTC continue to run, Video Enable status flag is reset, and the "Start Display" command must be given to reenable the display.

4. LOAD CURSOR POSITION

	OPERATION	C/P	DESCRIPTION	DATA BUS MSB LSB
Command	Write	1	Load Cursor	1 0 0 0 0 0 0 0
Parameters	Write Write	0 0	Char. Number Row Number	(Char. Position in Row) (Row Number)

Action—The 8276 is conditioned to place the next two parameter bytes into the cursor position registers. Status flag not affected.

5. ENABLE INTERRUPT COMMAND

	OPERATION	C/P	DESCRIPTION	DATA BUS MSB LSB
Command	Write	1	Enable Interrupt	1 0 1 0 0 0 0 0
No parameters				

Action—The interrupt enable flag is set and interrupts are enabled.

6. DISABLE INTERRUPT COMMAND

	OPERATION	C/P	DESCRIPTION	DATA BUS MSB LSB
Command	Write	1	Disable Interrupt	1 1 0 0 0 0 0 0
No parameters				

Action—Interrupts are disabled and the interrupt enable status flag is reset.

7. PRESET COUNTERS COMMAND

	OPERATION	C/P	DESCRIPTION	DATA BUS MSB LSB
Command	Write	1	Preset Counters	1 1 1 0 0 0 0 0
No parameters				

Action—The internal timing counters are preset, corresponding to a screen display position at the top left corner. Two character clocks are required for this operation. The counters will remain in this state until any other command is given.

This command is useful for system debug and synchronization of clustered CRT displays on a single CPU.

Status Flags

	OPERATION	C/P	DESCRIPTION	DATA BUS MSB LSB
Command	Read	1	Status Word	0 IE IR X IC VE BU X

IE — (Interrupt Enable) Set or reset by command. It enables vertical retrace interrupt. It is automatically set by a "Start Display" command and reset with the "Reset" command.

IR — (Interrupt Request) This flag is set at the beginning of display of the last row of the frame if the interrupt enable flag is set. It is reset after a status read operation.

IC — (Improper Command) This flag is set when a command parameter string is too long or too short. The flag is automatically reset after a status read.

VE — (Video Enable) This flag indicates that video operation of the CRT is enabled. This flag is set on a "Start Display" command, and reset on a "Stop Display" or "Reset" command.

BU — (Buffer Underrun) This flag is set whenever a Row Buffer is not filled with character data in time for a buffer swap required by the display. Upon activation of this bit, buffer loading ceases, and the screen is blanked until after the vertical retrace interval.

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias .... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage On Any Pin
With Respect to Ground ..... −0.5V to +7V
Power Dissipation ..... 1 Watt

*NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

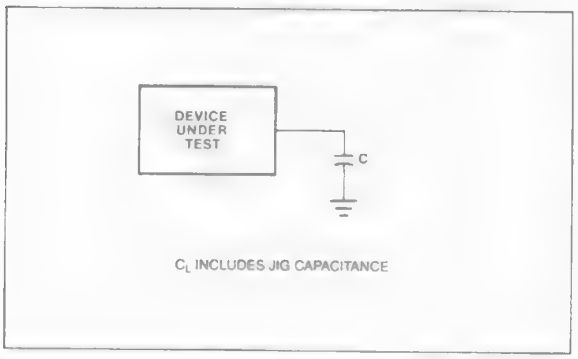
D.C. CHARACTERISTICS (T_A = 0°C to 70°C; V_{CC} = 5V ±5%)

SYMBOL	PARAMETER	MIN.	MAX.	UNITS	TEST CONDITIONS
V_{IL}	Input Low Voltage	−0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.5V	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2.2 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400 μA
I_{IL}	Input Load Current		±10	μA	V_{IN} = V_{CC} to 0V
I_{OFL}	Output Float Leakage		±10	μA	V_{OUT} = V_{CC} to 0.45V
I_{CC}	V_{CC} Supply Current		160	mA	

CAPACITANCE (T_A = 25°C; V_{CC} = GND = 0V)

SYMBOL	PARAMETER	MIN.	MAX.	UNITS	TEST CONDITIONS
C_{IN}	Input Capacitance		10	pF	f_C = 1 MHz
$C_{I/O}$	I/O Capacitance		20	pF	Unmeasured pins returned to V_{SS}.

A.C. TESTING LOAD CIRCUIT



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A.C. CHARACTERISTICS (T_A = 0°C to 70°C; V_{CC} = 5.0V ±5%; GND = 0V)

Bus Parameters

READ CYCLE

Symbol	Parameter	Min.	Max.	Units	Test Conditions
t_{AR}	Address Stable Before READ	0		ns	
t_{RA}	Address Hold Time for READ	0		ns	
t_{RR}	READ Pulse Width	250		ns	
t_{RD}	Data Delay from READ		200	ns	C_L = 150pF
t_{DF}	READ to Data Floating		100	ns	

WRITE CYCLE

Symbol	Parameter	Min.	Max.	Units	Test Conditions
t_{AW}	Address Stable Before WRITE	0		ns	
t_{WA}	Address Hold Time for WRITE	0		ns	
t_{WW}	WRITE Pulse Width	250		ns	
t_{DW}	Data Setup Time for WRITE	150		ns	
t_{WD}	Data Hold Time for WRITE	0		ns	

CLOCK TIMING

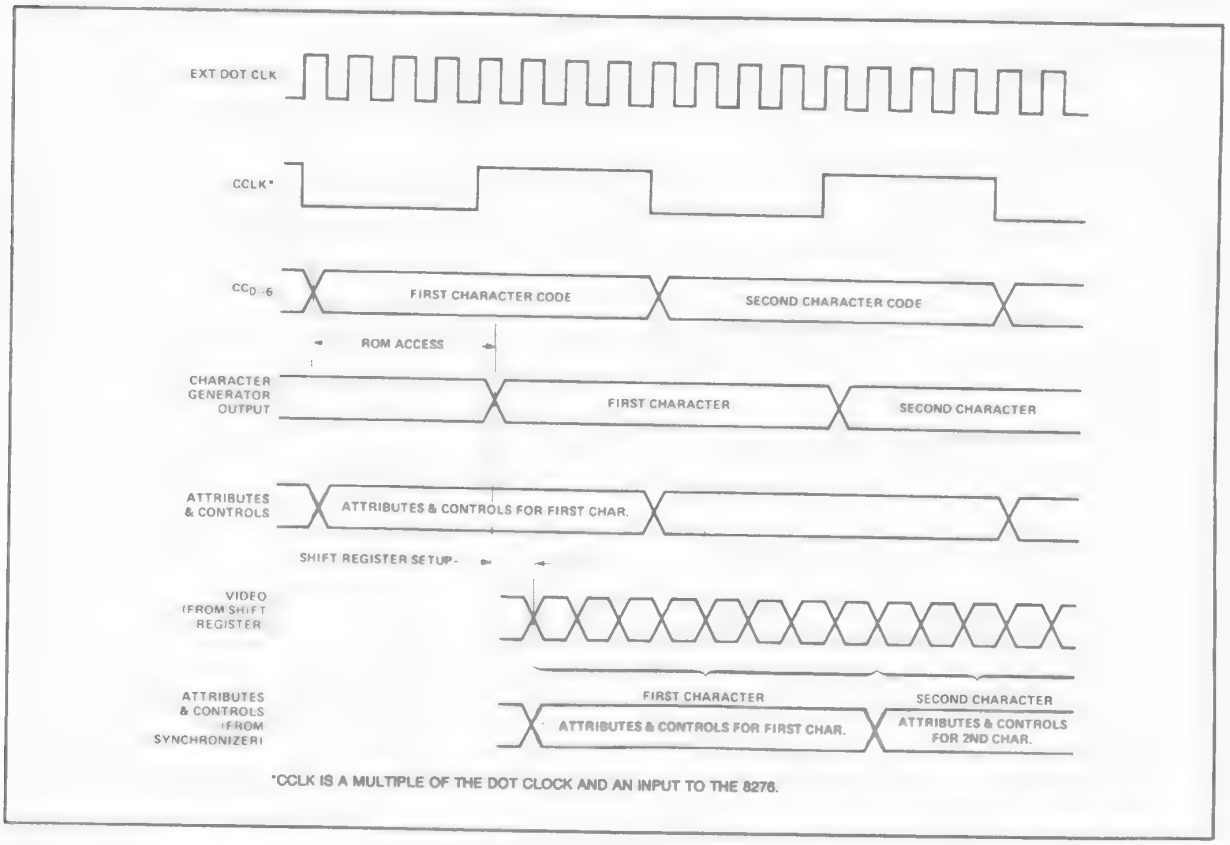
		8276		8276-2			
Symbol	Parameter	Min.	Max.	Min.	Max.	Units	Test Conditions
t_{CLK}	Clock Period	480		320		ns	
t_{KH}	Clock High	240		120		ns	
t_{KL}	Clock Low	160		120		ns	
t_{KR}	Clock Rise	5	30	5	30	ns	
t_{KF}	Clock Fall	5	30	5	30	ns	

OTHER TIMING

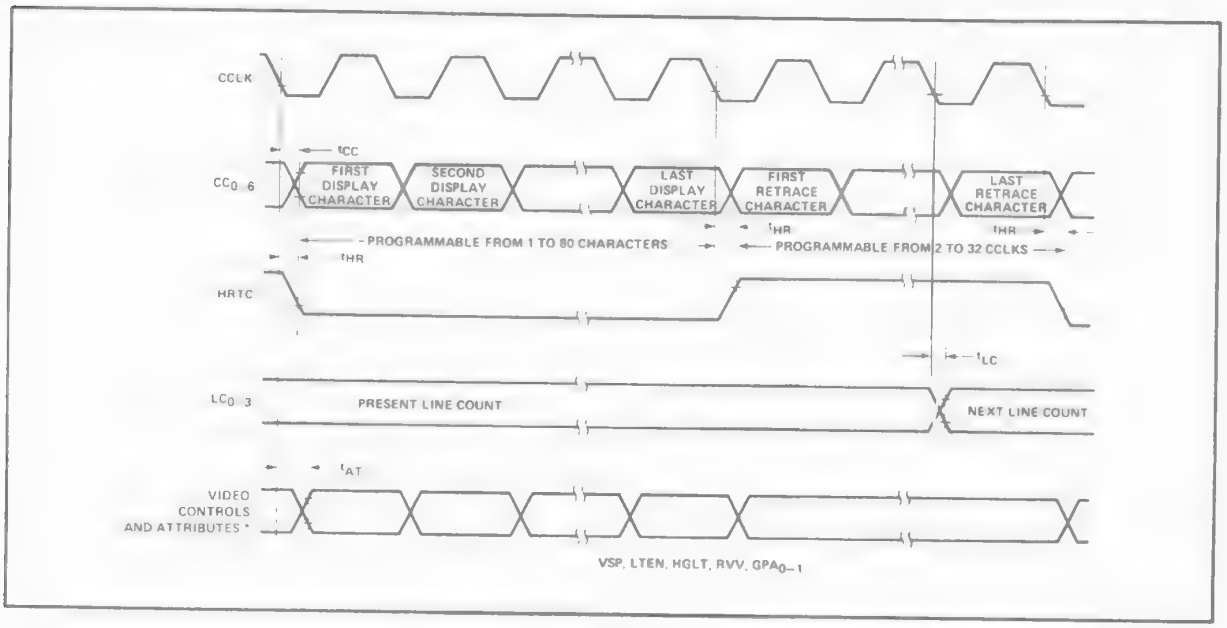
		8276		8276-2			
Symbol	Parameter	Min.	Max.	Min.	Max.	Units	Test Conditions
t_{CC}	Character Code Output Delay		150		150	ns	CL = 50 pF
t_{HR}	Horizontal Retrace Output Delay		200		150	ns	C_L = 50 pF
t_{LC}	Line Count Output Delay		400		250	ns	C_L = 50 pF
t_{AT}	Control/Attribute Output Delay		275		250	ns	C_L = 50 pF
t_{VR}	Vertical Retrace Output Delay		275		250	ns	C_L = 50 pF
t_{RI}	INT↓ from $\overline{RD}$↑		250		250	ns	C_L = 50 pF
t_{WQ}	BRDY↑ from $\overline{WR}$↑		250		250	ns	C_L = 50 pF
t_{RQ}	BRDY↓ from $\overline{WR}$↓		200		200	ns	C_L = 50 pF
t_{LR}	$\overline{BS}$↓ to $\overline{WR}$↓	0		0		ns	
t_{RL}	$\overline{WR}$↑ to $\overline{BS}$↑	0		0		ns	

WAVEFORMS

Typical Dot Level Timing



Line Timing



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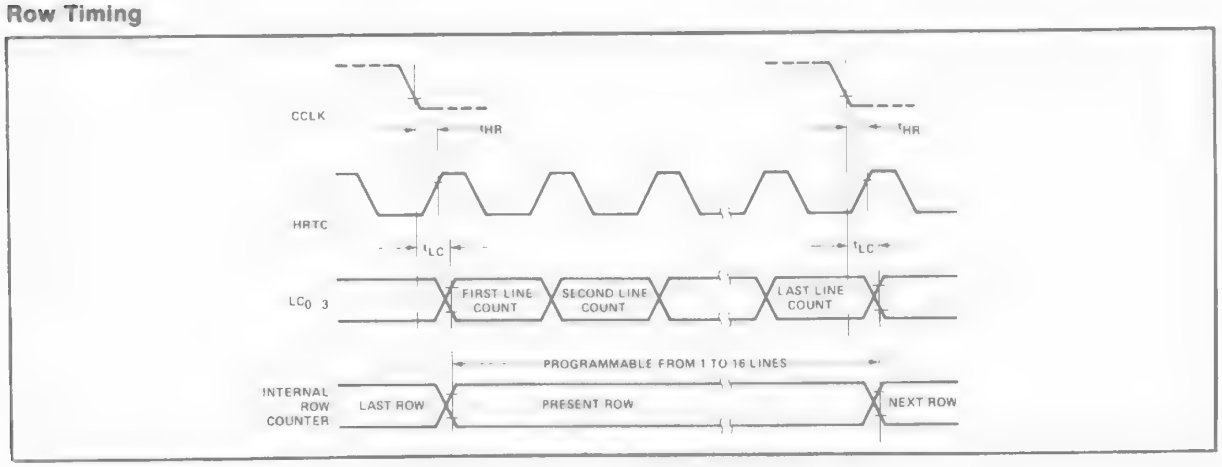
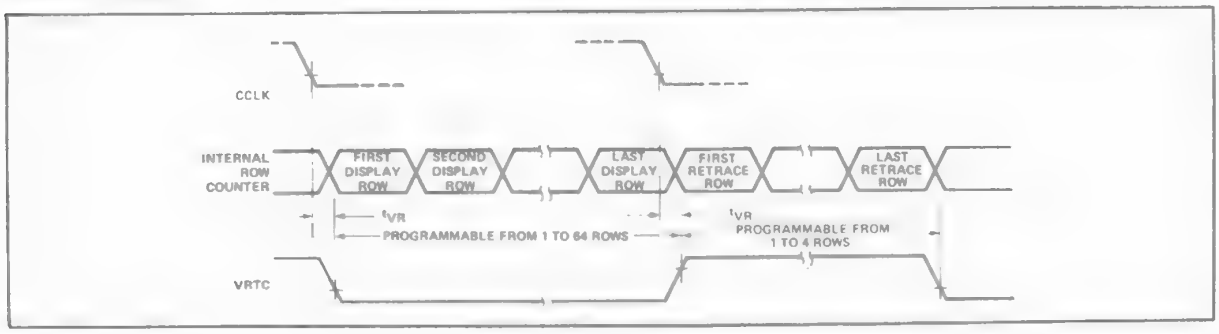
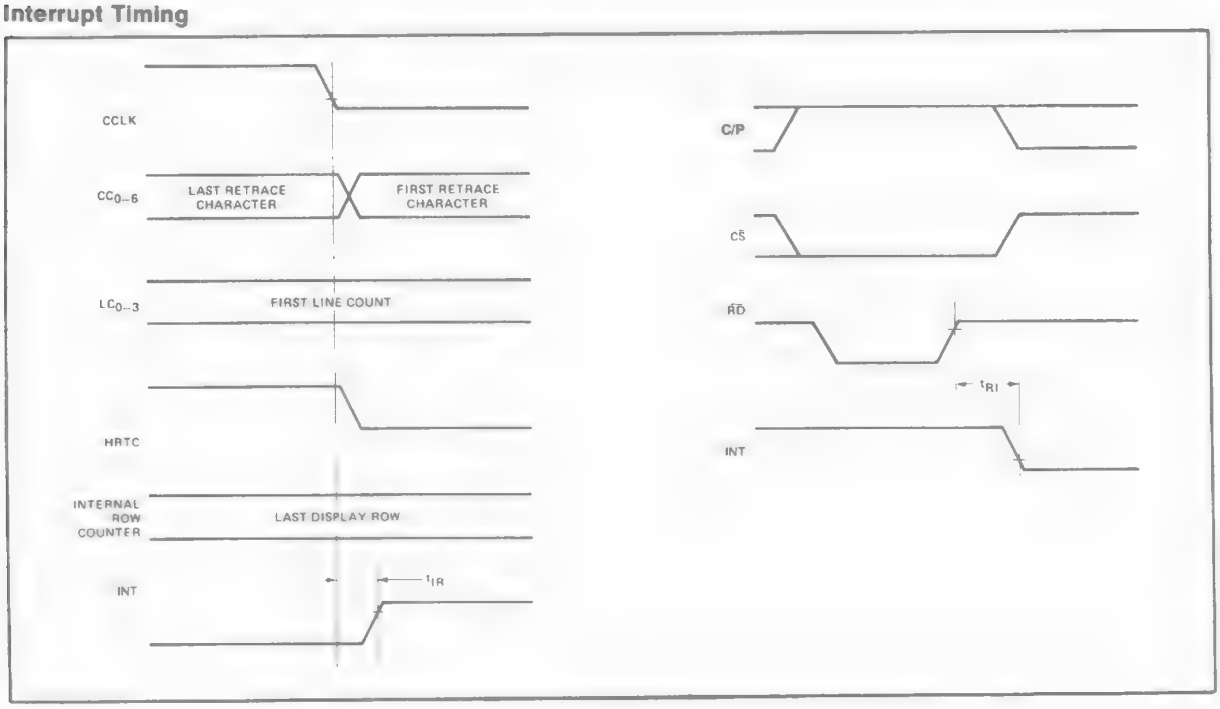
Row Timing



Frame Timing



Interrupt Timing



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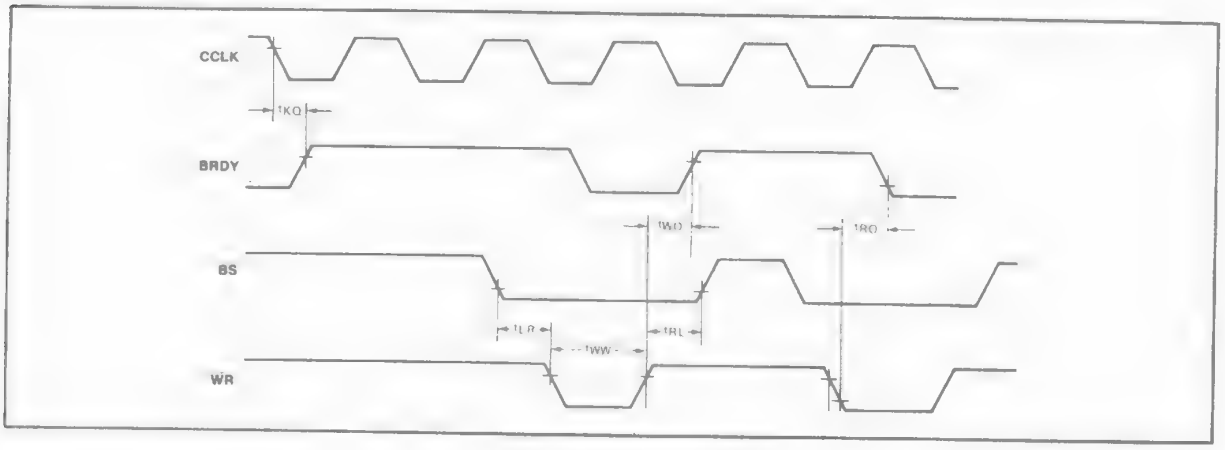
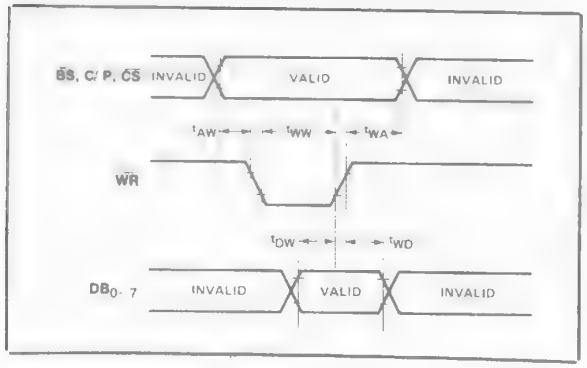
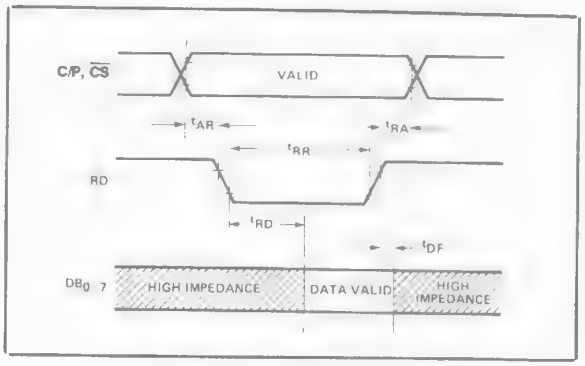
Timing for Buffer Loading



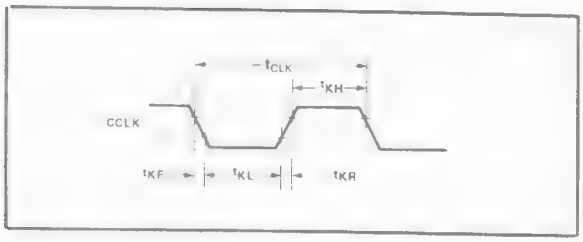
Write Timing



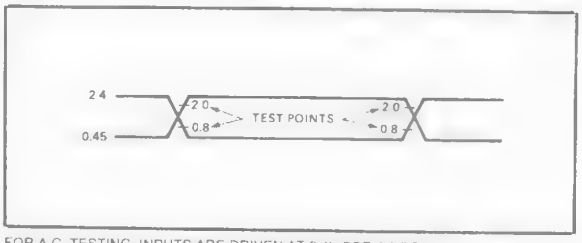
Read Timing



Clock Timing



Input and Output Waveforms for A.C. Tests



FOR A.C. TESTING, INPUTS ARE DRIVEN AT 2.4V FOR A LOGIC "1" AND 0.45V FOR A LOGIC "0". TIMING MEASUREMENTS FOR INPUT AND OUTPUT SIGNALS ARE MADE AT 2.0V FOR A LOGIC "1" AND 0.8V FOR A LOGIC "0".

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8279/8279-5
PROGRAMMABLE KEYBOARD/DISPLAY INTERFACE

- Simultaneous Keyboard Display Operations
- Scanned Keyboard Mode
- Scanned Sensor Mode
- Strobed Input Entry Mode
- 8-Character Keyboard FIFO
- 2-Key Lockout or N-Key Rollover with Contact Debounce
- Dual 8- or 16-Numerical Display
- Single 16-Character Display
- Right or Left Entry 16-Byte Display RAM
- Mode Programmable from CPU
- Programmable Scan Timing
- Interrupt Output on Key Entry
- Available in EXPRESS
  - —Standard Temperature Range
  - —Extended Temperature Range

The Intel® 8279 is a general purpose programmable keyboard and display I/O interface device designed for use with Intel® microprocessors. The keyboard portion can provide a scanned interface to a 64-contact key matrix. The keyboard portion will also interface to an array of sensors or a strobed interface keyboard, such as the hall effect and ferrite variety. Key depressions can be 2-key lockout or N-key rollover. Keyboard entries are debounced and strobed in an 8-character FIFO. If more than 8 characters are entered, overrun status is set. Key entries set the interrupt output line to the CPU.

The display portion provides a scanned display interface for LED, incandescent, and other popular display technologies. Both numeric and alphanumeric segment displays may be used as well as simple indicators. The 8279 has 16X8 display RAM which can be organized into dual 16X4. The RAM can be loaded or interrogated by the CPU. Both right entry, calculator and left entry typewriter display formats are possible. Both read and write of the display RAM can be done with auto-increment of the display RAM address.

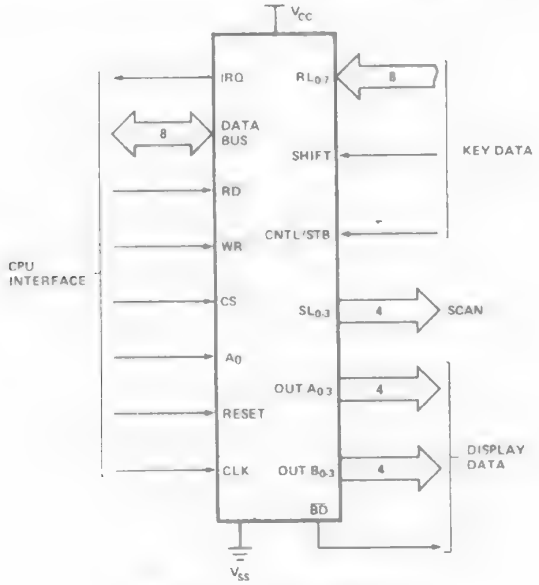

Figure 1. Logic Symbol

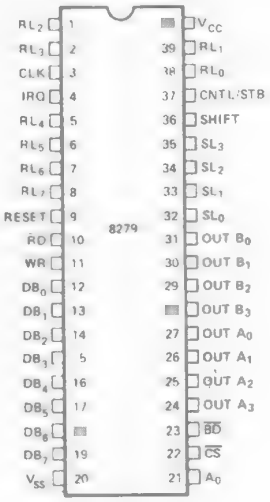

Figure 2. Pin Configuration

HARDWARE DESCRIPTION

The 8279 is packaged in a 40 pin DIP. The following is a functional description of each pin.

Table 1. Pin Descriptions

Symbol	Pin No.	Name and Function
DB_0-DB_7	8	**Bi-directional data bus:** All data and commands between the CPU and the 8279 are transmitted on these lines.
CLK	1	**Clock:** Clock from system used to generate internal timing.
RESET	1	**Reset:** A high signal on this pin resets the 8279. After being reset the 8279 is placed in the following mode: 1) 16 8-bit character display —left entry. 2) Encoded scan keyboard—2 key lockout. Along with this the program clock prescaler is set to 31.
CS	1	**Chip Select:** A low on this pin enables the interface functions to receive or transmit.
A_0	1	**Buffer Address:** A high on this line indicates the signals in or out are interpreted as a command or status. A low indicates that they are data.
$\overline{RD}$, $\overline{WR}$	2	**Input/Output Read and Write:** These signals enable the data buffers to either send data to the external bus or receive it from the external bus.
IRQ	1	**Interrupt Request:** In a keyboard mode, the interrupt line is high when there is data in the FIFO/Sensor RAM. The interrupt line goes low with each FIFO/Sensor RAM read and returns high if there is still information in the RAM. In a sensor mode, the interrupt line goes high whenever a change in a sensor is detected.
V_{SS}, V_{CC}	2	**Ground and power supply pins.**
SL_0–SL_3	4	**Scan Lines:** Scan lines which are used to scan the key switch or sensor matrix and the display digits. These lines can be either encoded (1 of 16) or decoded (1 of 4).
RL_0–RL_7	8	**Return Line:** Return line inputs which are connected to the scan lines through the keys or sensor switches. They have active internal pullups to keep them high until a switch closure pulls one low. They also serve as an 8-bit input in the Strobed Input mode.
SHIFT	1	**Shift:** The shift input status is stored along with the key position on key closure in the Scanned Keyboard modes. It has an active internal pullup to keep it high until a switch closure pulls it low.
CNTL/STB	1	**Control/Strobed Input Mode:** For keyboard modes this line is used as a control input and stored like status on a key closure. The line is also the strobe line that enters the data into the FIFO in the Strobed Input mode. (Rising Edge). It has an active internal pullup to keep it high until a switch closure pulls it low.
OUT A_0–OUT A_3 OUT B_0–OUT B_3	8 8	**Outputs:** These two ports are the outputs for the 16 x 4 display refresh registers. The data from these outputs is synchronized to the scan lines (SL_0–SL_3) for multiplexed digit displays. The two 4 bit ports may be blanked independently. These two ports may also be considered as one 8-bit port.
$\overline{BD}$	1	**Blank Display:** This output is used to blank the display during digit switching or by a display blanking command.

FUNCTIONAL DESCRIPTION

Since data input and display are an integral part of many microprocessor designs, the system designer needs an interface that can control these functions without placing a large load on the CPU. The 8279 provides this function for 8-bit microprocessors.

The 8279 has two sections: keyboard and display. The keyboard section can interface to regular typewriter style keyboards or random toggle or thumb switches. The display section drives alphanumeric displays or a bank of indicator lights. Thus the CPU is relieved from scanning the keyboard or refreshing the display.

The 8279 is designed to directly connect to the microprocessor bus. The CPU can program all operating modes for the 8279. These modes include:

Input Modes

- Scanned Keyboard — with encoded (8 x 8 key keyboard) or decoded (4 x 8 key keyboard) scan lines. A key depression generates a 6-bit encoding of key position. Position and shift and control status are stored in the FIFO. Keys are automatically debounced with 2-key lockout or N-key rollover.
- Scanned Sensor Matrix — with encoded (8 x 8 matrix switches) or decoded (4 x 8 matrix switches) scan lines. Key status (open or closed) stored in RAM addressable by CPU.
- Strobed Input — Data on return lines during control line strobe is transferred to FIFO.

Output Modes

- 8 or 16 character multiplexed displays that can be organized as dual 4-bit or single 8-bit ($B_0 = D_0$, $A_3 = D_7$).
- Right entry or left entry display formats.

Other features of the 8279 include:

- Mode programming from the CPU.
- Clock Prescaler
- Interrupt output to signal CPU when there is keyboard or sensor data available.
- An 8 byte FIFO to store keyboard information
- 16 byte internal Display RAM for display refresh. This RAM can also be read by the CPU.

PRINCIPLES OF OPERATION

The following is a description of the major elements of the 8279 Programmable Keyboard/Display interface device. Refer to the block diagram in Figure 3.

I/O Control and Data Buffers

The I/O control section uses the $\overline{CS}$, A_0, $\overline{RD}$ and $\overline{WR}$ lines to control data flow to and from the various internal registers and buffers. All data flow to and from the 8279 is enabled by $\overline{CS}$. The character of the information, given or desired by the CPU, is identified by A_0. A logic one means the information is a command or status. A logic zero means the information is data. $\overline{RD}$ and $\overline{WR}$ determine the direction of data flow through the Data Buffers. The Data Buffers are bi-directional buffers that connect the internal bus to the external bus. When the chip is not selected ($\overline{CS}$ = 1), the devices are in a high impedance state. The drivers input during $\overline{WR} \bullet \overline{CS}$ and output during $\overline{RD} \bullet \overline{CS}$.

Control and Timing Registers and Timing Control

These registers store the keyboard and display modes and other operating conditions programmed by the CPU. The modes are programmed by presenting the proper command on the data lines with $A_0 = 1$ and then sending a WR. The command is latched on the rising edge of $\overline{WR}$.

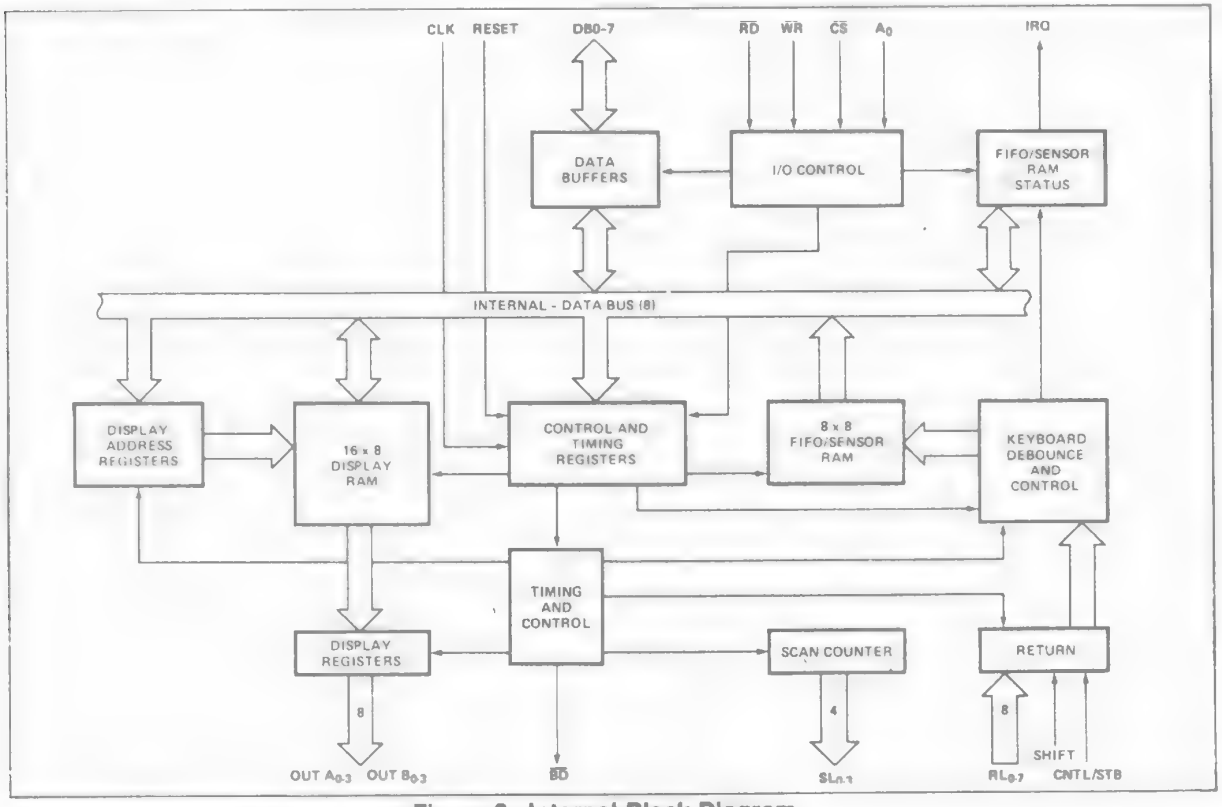

Figure 3. Internal Block Diagram

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The command is then decoded and the appropriate function is set. The timing control contains the basic timing counter chain. The first counter is a ÷ N prescaler that can be programmed to yield an internal frequency of 100 kHz which gives a 5.1 ms keyboard scan time and a 10.3 ms debounce time. The other counters divide down the basic internal frequency to provide the proper key scan, row scan, keyboard matrix scan, and display scan times.

Scan Counter

The scan counter has two modes. In the encoded mode, the counter provides a binary count that must be externally decoded to provide the scan lines for the keyboard and display. In the decoded mode, the scan counter decodes the least significant 2 bits and provides a decoded 1 of 4 scan. Note than when the keyboard is in decoded scan, so is the display. This means that only the first 4 characters in the Display RAM are displayed.

In the encoded mode, the scan lines are active high outputs. In the decoded mode, the scan lines are active low outputs.

Return Buffers and Keyboard Debounce and Control

The 8 return lines are buffered and latched by the Return Buffers. In the keyboard mode, these lines are scanned, looking for key closures in that row. If the debounce circuit detects a closed switch, it waits about 10 msec to check if the switch remains closed. If it does, the address of the switch in the matrix plus the status of SHIFT and CONTROL are transferred to the FIFO. In the scanned Sensor Matrix modes, the contents of the return lines is directly transferred to the corresponding row of the Sensor RAM (FIFO) each key scan time. In Strobed Input mode, the contents of the return lines are transferred to the FIFO on the rising edge of the CNTL/STB line pulse.

FIFO/Sensor RAM and Status

This block is a dual function 8 x 8 RAM. In Keyboard or Strobed Input modes, it is a FIFO. Each new entry is written into successive RAM positions and each is then read in order of entry. FIFO status keeps track of the number of characters in the FIFO and whether it is full or empty. Too many reads or writes will be recognized as an error. The status can be read by an $\overline{RD}$ with $\overline{CS}$ low and A_0 high. The status logic also provides an IRQ signal when the FIFO is not empty. In Scanned Sensor Matrix mode, the memory is a Sensor RAM. Each row of the Sensor RAM is loaded with the status of the corresponding row of sensor in the sensor matrix. In this mode, IRQ is high if a change in a sensor is detected.

Display Address Registers and Display RAM

The Display Address Registers hold the address of the word currently being written or read by the CPU and the two 4-bit nibbles being displayed. The read/write addresses are programmed by CPU command. They also can be set to auto increment after each read or write. The Display RAM can be directly read by the CPU after the correct mode and address is set. The addresses for the A and B nibbles are automatically updated by the 8279 to match data entry by the CPU. The A and B nibbles can be entered independently or as one word, according to the mode that is set by the CPU. Data entry to the display can be set to either left or right entry. See Interface Considerations for details.

SOFTWARE OPERATION

8279 commands

The following commands program the 8279 operating modes. The commands are sent on the Data Bus with $\overline{CS}$ low and A_0 high and are loaded to the 8279 on the rising edge of $\overline{WR}$.

Keyboard/Display Mode Set

	MSB							LSB
Code:	0	0	0	D	D	K	K	K

Where DD is the Display Mode and KKK is the Keyboard Mode.

DD

0	0	8 8-bit character display — Left entry
0	1	16 8-bit character display — Left entry*
1	0	8 8-bit character display — Right entry
1	1	16 8-bit character display — Right entry

For description of right and left entry, see Interface Considerations. Note that when decoded scan is set in keyboard mode, the display is reduced to 4 characters independent of display mode set.

KKK

0	0	0	Encoded Scan Keyboard — 2 Key Lockout*
0	0	1	Decoded Scan Keyboard — 2-Key Lockout
0	1	0	Encoded Scan Keyboard — N-Key Rollover
0	1	1	Decoded Scan Keyboard — N-Key Rollover
1	0	0	Encoded Scan Sensor Matrix
1	0	1	Decoded Scan Sensor Matrix
1	1	0	Strobed Input, Encoded Display Scan
1	1	1	Strobed Input, Decoded Display Scan

Program Clock

Code:	0	0	1	P	P	P	P	P

All timing and multiplexing signals for the 8279 are generated by an internal prescaler. This prescaler divides the external clock (pin 3) by a programmable integer. Bits PPPPP determine the value of this integer which ranges from 2 to 31. Choosing a divisor that yields 100 kHz will give the specified scan and debounce times. For instance, if Pin 3 of the 8279 is being clocked by a 2 MHz signal, PPPPP should be set to 10100 to divide the clock by 20 to yield the proper 100 kHz operating frequency.

Read FIFO/Sensor RAM

Code:	0	1	0	AI	X	A	A	A

X = Don't Care

The CPU sets up the 8279 for a read of the FIFO/Sensor RAM by first writing this command. In the Scan Key-

*Default after reset

board Mode, the Auto-Increment flag (AI) and the RAM address bits (AAA) are irrelevant. The 8279 will automatically drive the data bus for each subsequent read ($A_0 = 0$) in the same sequence in which the data first entered the FIFO. All subsequent reads will be from the FIFO until another command is issued.

In the Sensor Matrix Mode, the RAM address bits AAA select one of the 8 rows of the Sensor RAM. If the AI flag is set (AI = 1), each successive read will be from the subsequent row of the sensor RAM.

Read Display RAM

Code:

0	1	1	AI	A	A	A	A

The CPU sets up the 8279 for a read of the Display RAM by first writing this command. The address bits AAAA select one of the 16 rows of the Display RAM. If the AI flag is set (AI = 1), this row address will be incremented after each following read *or write* to the Display RAM. Since the same counter is used for both reading and writing, this command sets the next read *or write* address and the sense of the Auto-Increment mode for both operations.

Write Display RAM

Code:

1	0	0	AI	A	A	A	A

The CPU sets up the 8279 for a write to the Display RAM by first writing this command. After writing the command with $A_0 = 1$, all subsequent writes with $A_0 = 0$ will be to the Display RAM. The addressing and Auto-Increment functions are identical to those for the Read Display RAM. However, this command does not affect the source of subsequent Data Reads; the CPU will read from whichever RAM (Display or FIFO/Sensor) which was last specified. If, indeed, the Display RAM was last specified, the Write Display RAM will, nevertheless, change the next Read location.

Display Write Inhibit/Blanking

Code:

				A	B	A	B
1	0	1	X	IW	IW	BL	BL

The IW Bits can be used to mask nibble A and nibble B in applications requiring separate 4-bit display ports. By setting the IW flag (IW = 1) for one of the ports, the port becomes marked so that entries to the Display RAM from the CPU do not affect that port. Thus, if each nibble is input to a BCD decoder, the CPU may write a digit to the Display RAM without affecting the other digit being displayed. It is important to note that bit B_0 corresponds to bit D_0 on the CPU bus, and that bit A_3 corresponds to bit D_7.

If the user wishes to blank the display, the BL flags are available for each nibble. The last Clear command issued determines the code to be used as a "blank." This code defaults to all zeros after a reset. Note that both BL flags must be set to blank a display formatted with a single 8-bit port.

Clear

Code:

1	1	0	C_D	C_D	C_D	C_F	C_A

The C_D bits are available in this command to clear all rows of the Display RAM to a selectable blanking code as follows:

C_D	C_D	C_D	
0	X		All Zeros (X = Don't Care)
1	0		AB = Hex 20 (0010 0000)
1	1		All Ones

Enable clear display when = 1 (or by C_A = 1)

During the time the Display RAM is being cleared (~160 μs), it may not be written to. The most significant bit of the FIFO status word is set during this time. When the Display RAM becomes available again, it automatically resets.

If the C_F bit is asserted ($C_F = 1$), the FIFO status is cleared and the interrupt output line is reset. Also, the Sensor RAM pointer is set to row 0.

C_A, the Clear All bit, has the combined effect of C_D and C_F; it uses the C_D clearing code on the Display RAM and also clears FIFO status. Furthermore, it resynchronizes the internal timing chain.

End Interrupt/Error Mode Set

Code:

1	1	1	E	X	X	X	X

X = Don't care

For the sensor matrix modes this command lowers the IRQ line and enables further writing into RAM. (The IRQ line would have been raised upon the detection of a change in a sensor value. This would have also inhibited further writing into the RAM until reset).

For the N-key rollover mode — if the E bit is programmed to "1" the chip will operate in the special Error mode. (For further details, see Interface Considerations Section.)

Status Word

The status word contains the FIFO status, error, and display unavailable signals. This word is read by the CPU when A_0 is high and $\overline{CS}$ and $\overline{RD}$ are low. See Interface Considerations for more detail on status word.

Data Read

Data is read when A_0, $\overline{CS}$ and $\overline{RD}$ are all low. The source of the data is specified by the Read FIFO or Read Display commands. The trailing edge of $\overline{RD}$ will cause the address of the RAM being read to be incremented if the Auto-Increment flag is set. FIFO reads always increment (if no error occurs) independent of AI.

Data Write

Data that is written with A_0, $\overline{CS}$ and $\overline{WR}$ low is always written to the Display RAM. The address is specified by the latest Read Display or Write Display command. Auto-Incrementing on the rising edge of $\overline{WR}$ occurs if AI set by the latest display command.

INTERFACE CONSIDERATIONS

Scanned Keyboard Mode, 2-Key Lockout

There are three possible combinations of conditions that can occur during debounce scanning. When a key is depressed, the debounce logic is set. Other depressed keys are looked for during the next two scans. If none are encountered, it is a single key depression and the key position is entered into the FIFO along with the status of CNTL and SHIFT lines. If the FIFO was empty, IRQ will be set to signal the CPU that there is an entry in the FIFO. If the FIFO was full, the key will not be entered and the error flag will be set. If another closed switch is encountered, no entry to the FIFO can occur. If all other keys are released before this one, then it will be entered to the FIFO. If this key is released before any other, it will be entirely ignored. A key is entered to the FIFO only once per depression, no matter how many keys were pressed along with it or in what order they were released. If two keys are depressed within the debounce cycle, it is a simultaneous depression. Neither key will be recognized until one key remains depressed alone. The last key will be treated as a single key depression.

Scanned Keyboard Mode, N-Key Rollover

With N-key Rollover each key depression is treated independently from all others. When a key is depressed, the debounce circuit waits 2 keyboard scans and then checks to see if the key is still down. If it is, the key is entered into the FIFO. Any number of keys can be depressed and another can be recognized and entered into the FIFO. If a simultaneous depression occurs, the keys are recognized and entered according to the order the keyboard scan found them.

Scanned Keyboard — Special Error Modes

For N-key rollover mode the user can program a special error mode. This is done by the "End Interrupt/Error Mode Set" command. The debounce cycle and key-validity check are as in normal N-key mode. If during a single debounce cycle, two keys are found depressed, this is considered a simultaneous multiple depression, and sets an error flag. This flag will prevent any further writing into the FIFO and will set interrupt (if not yet set). The error flag could be read in this mode by reading the FIFO STATUS word. (See "FIFO STATUS" for further details.) The error flag is reset by sending the normal CLEAR command with $C_F = 1$.

Sensor Matrix Mode

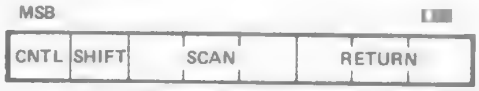
In Sensor Matrix mode, the debounce logic is inhibited. The status of the sensor switch is inputted directly to the Sensor RAM. In this way the Sensor RAM keeps an image of the state of the switches in the sensor matrix. Although debouncing is not provided, this mode has the advantage that the CPU knows how long the sensor was closed and when it was released. A keyboard mode can only indicate a validated closure. To make the software easier, the designer should functionally group the sensors by row since this is the format in which the CPU will read them.

The IRQ line goes high if any sensor value change is detected at the end of a sensor matrix scan. The IRQ line is cleared by the first data read operation if the Auto-Increment flag is set to zero, or by the End Interrupt command if the Auto-Increment flag is set to one.

Note: Multiple changes in the matrix Addressed by ($SL_{0-3} = 0$) may cause multiple interrupts. ($SL_0 = 0$ in the Decoded Mode). Reset may cause the 8279 to see multiple changes.

Data Format

In the Scanned Keyboard mode, the character entered into the FIFO corresponds to the position of the switch in the keyboard plus the status of the CNTL and SHIFT lines (non-inverted). CNTL is the MSB of the character and SHIFT is the next most significant bit. The next three bits are from the scan counter and indicate the row the key was found in. The last three bits are from the column counter and indicate to which return line the key was connected.



SCANNED KEYBOARD DATA FORMAT

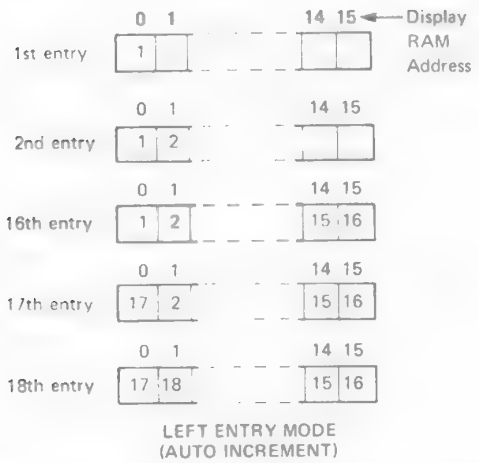
In Sensor Matrix mode, the data on the return lines is entered directly in the row of the Sensor RAM that corresponds to the row in the matrix being scanned. Therefore, each switch postion maps directly to a Sensor RAM position. The SHIFT and CNTL inputs are ignored in this mode. Note that switches are not necessarily the only thing that can be connected to the return lines in this mode. Any logic that can be triggered by the scan lines can enter data to the return line inputs. Eight multiplexed input ports could be tied to the return lines and scanned by the 8279.

In Strobed Input mode, the data is also entered to the FIFO from the return lines. The data is entered by the rising edge of a CNTL/STB line pulse. Data can come from another encoded keyboard or simple switch matrix. The return lines can also be used as a general purpose strobed input.

Display

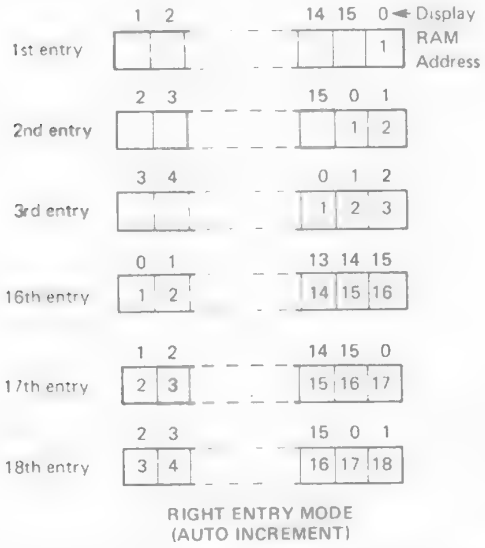
Left Entry

Left Entry mode is the simplest display format in that each display position directly corresponds to a byte (or nibble) in the Display RAM. Address 0 in the RAM is the left-most display character and address 15 (or address 7 in 8 character display) is the right most display character. Entering characters from position zero causes the display to fill from the left. The 17th (9th) character is entered back in the left most position and filling again proceeds from there.



Right Entry

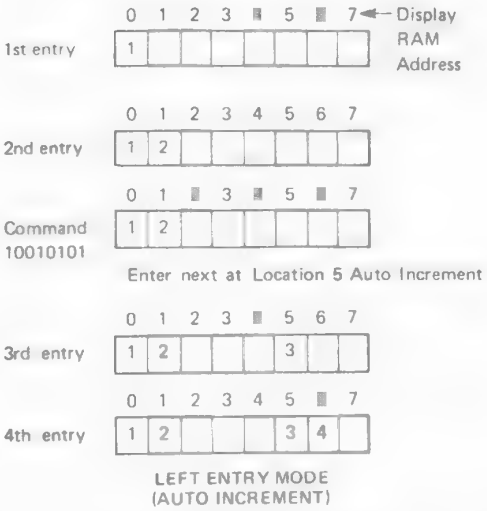
Right entry is the method used by most electronic calculators. The first entry is placed in the right most display character. The next entry is also placed in the right most character after the display is shifted left one character. The left most character is shifted off the end and is lost.



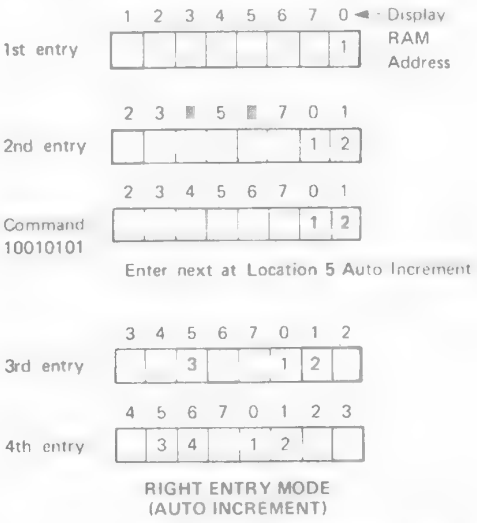
Note that now the display position and register address do not correspond. Consequently, entering a character to an arbitrary position in the Auto Increment mode may have unexpected results. Entry starting at Display RAM address 0 with sequential entry is recommended.

Auto Increment

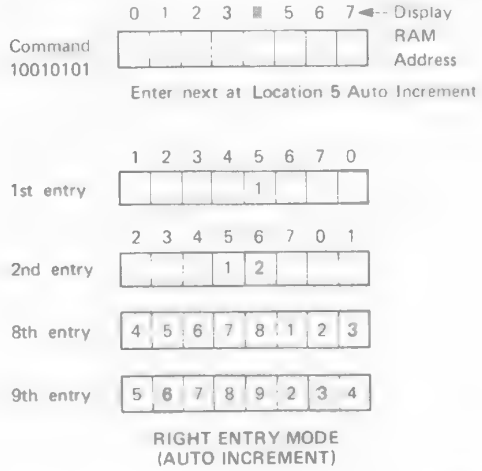
In the Left Entry mode, Auto Incrementing causes the address where the CPU will next write to be incremented by one and the character appears in the next location. With non-Auto Incrementing the entry is both to the same RAM address and display position. Entry to an arbitrary address in the Auto Increment mode has no undesirable side effects and the result is predictable:



In the Right Entry mode, Auto Incrementing and non Incrementing have the same effect as in the Left Entry except if the address sequence is interrupted:



Starting at an arbitrary location operates as shown below:



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Entry appears to be from the initial entry point.

8/16 Character Display Formats

If the display mode is set to an 8 character display, the on duty-cycle is double what it would be for a 16 character display (e.g., 5.1 ms scan time for 8 characters vs. 10.3 ms for 16 characters with 100 kHz internal frequency).

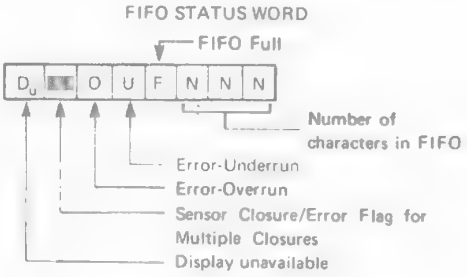
G. FIFO Status

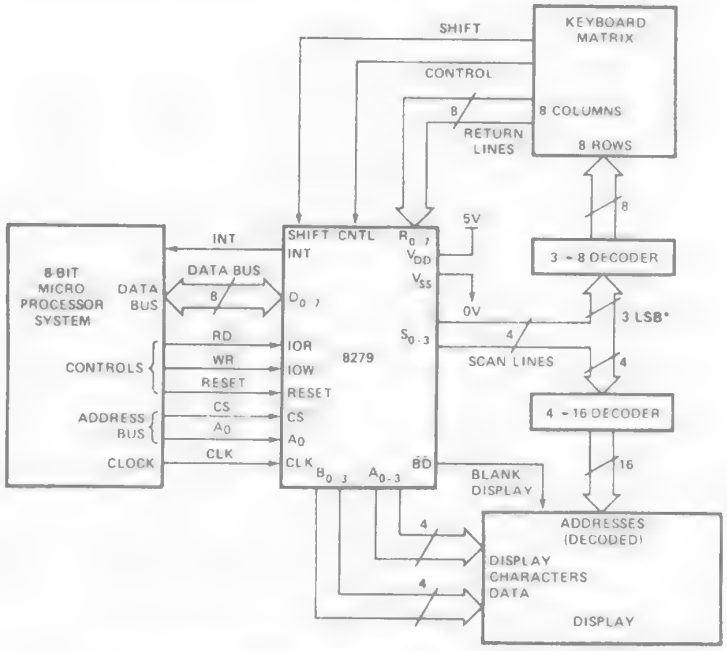
FIFO status is used in the Keyboard and Strobed Input modes to indicate the number of characters in the FIFO and to indicate whether an error has occurred. There are two types of errors possible: overrun and underrun. Overrun occurs when the entry of another character into a full FIFO is attempted. Underrun occurs when the CPU tries to read an empty FIFO.

The FIFO status word also has a bit to indicate that the Display RAM was unavailable because a Clear Display or Clear All command had not completed its clearing operation.

In a Sensor Matrix mode, a bit is set in the FIFO status word to indicate that at least one sensor closure indication is contained in the Sensor RAM.

In Special Error Mode the S/E bit is showing the error flag and serves as an indication to whether a simultaneous multiple closure error has occurred.





*Do not drive the keyboard decoder with the MSB of the scan lines

Figure 4. System Block Diagram

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature . . . . . 0°C to 70°C
Storage Temperature . . . . . -65°C to 125°C
Voltage on any Pin with
Respect to Ground . . . . . -0.5V to +7V
Power Dissipation . . . . . 1 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS [T_A = 0°C to 70°C, V_{SS} = V_{CC} = +5V ± 5%, V_{CC} = +5V ±10% (8279-5)] *

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_{IL1}	Input Low Voltage for Return Lines	-0.5	1.4	V	
V_{IL2}	Input Low Voltage for All Others	-0.5	0.8	V	
V_{IH1}	Input High Voltage for Return Lines	2.2		V	
V_{IH2}	Input High Voltage for All Others	2.0		V	
V_{OL}	Output Low Voltage		0.45	V	Note 1
V_{OH1}	Output High Voltage on Interrupt Line	3.5		V	Note 2
V_{OH2}	Other Outputs	2.4			I_{OH} = −400 μA
I_{IL1}	Input Current on Shift, Control and Return Lines		+10 -100	μA μA	V_{IN} = V_{CC} V_{IN} = 0V
I_{IL2}	Input Leakage Current on All Others		±10	μA	V_{IN} = V_{CC} to 0V
I_{OFL}	Output Float Leakage		±10	μA	V_{OUT} = V_{CC} to 0.45V
I_{CC}	Power Supply Current		120	mA	

CAPACITANCE

Symbol	Parameter	Typ.	Max.	Unit	Test Conditions
C_{IN}	Input Capacitance	5	10	pF	f_C = 1 MHz Unmeasured pins returned to V_{SS}
C_{OUT}	Output Capacitance	10	20	pF	

A.C. CHARACTERISTICS [T_A = 0°C to 70°C, V_{SS} = 0V, (Note 3)] *

Bus Parameters

READ CYCLE

Symbol	Parameter	8279		8279-5		Unit
		Min.	Max.	Min.	Max.	
t_{AR}	Address Stable Before $\overline{READ}$	50		0		ns
t_{RA}	Address Hold Time for $\overline{READ}$	5		0		ns
t_{RR}	$\overline{READ}$ Pulse Width	420		250		ns
t_{RD} [4]	Data Delay from $\overline{READ}$		300		150	ns
t_{AD} [4]	Address to Data Valid		450		250	ns
t_{DF}	$\overline{READ}$ to Data Floating	10	100	10	100	ns
t_{RCY}	Read Cycle Time	1		1		μs

A.C. CHARACTERISTICS (Continued)

WRITE CYCLE

Symbol	Parameter	8279 Min.	8279 Max.	8279-5 Min.	8279-5 Max.	Unit
t_{AW}	Address Stable Before $\overline{WRITE}$	50		0		ns
t_{WA}	Address Hold Time for $\overline{WRITE}$	20		0		ns
t_{WW}	$\overline{WRITE}$ Pulse Width	400		250		ns
t_{DW}	Data Set Up Time for $\overline{WRITE}$	300		150		ns
t_{WD}	Data Hold Time for $\overline{WRITE}$	40		0		ns
t_{WCY}	Write Cycle Time	1		1		μs

OTHER TIMINGS

Symbol	Parameter	8279 Min.	8279 Max.	8279-5 Min.	8279-5 Max.	Unit
$t_{\phi W}$	Clock Pulse Width	230		120		nsec
t_{CY}	Clock Period	500		320		nsec

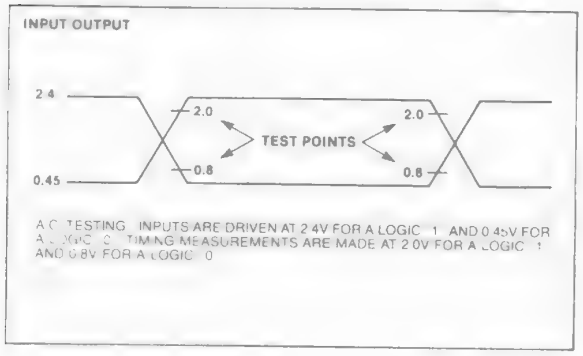
Keyboard Scan Time ..... 5.1 msec
Keyboard Debounce Time ..... 10.3 msec
Key Scan Time ..... 80 μsec
Display Scan Time ..... 10.3 msec

Digit-on Time ..... 480 μsec
Blanking Time ..... 160 μsec
Internal Clock Cycle[5] ..... 10 μsec

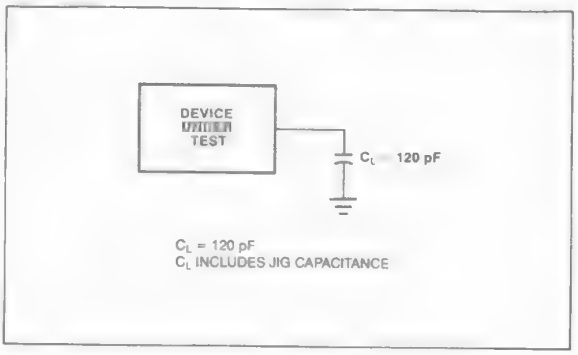
NOTES:
1. 8279, I_{OL} = 1.6mA; 8279-5, I_{OL} = 2.2mA.
2. I_{OH} = −100 μA
3. 8279, V_{CC} = +5V ±5%; 8279-5, V_{CC} = +5V ±10%.
4. 8279, C_L = 100pF; 8279-5, C_L = 150pF.
5. The Prescaler should be programmed to provide a 10 μs internal clock cycle.

* For Extended Temperature EXPRESS, use M8279A electrical parameters.

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING LOAD CIRCUIT



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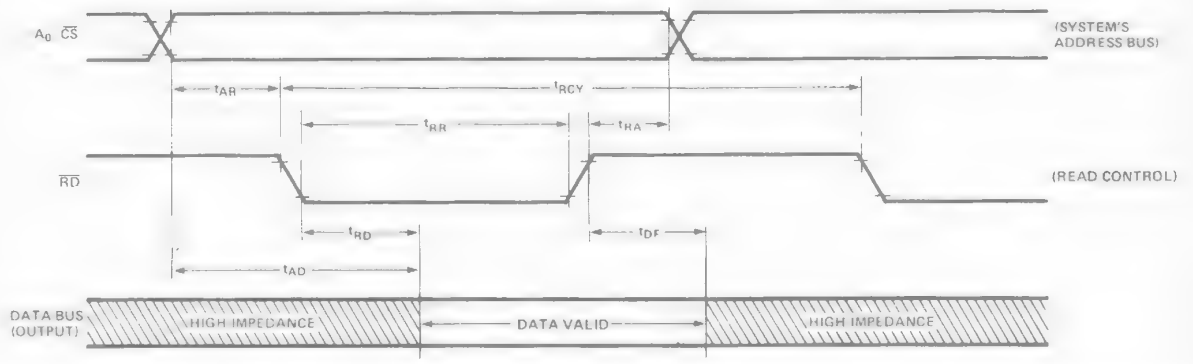
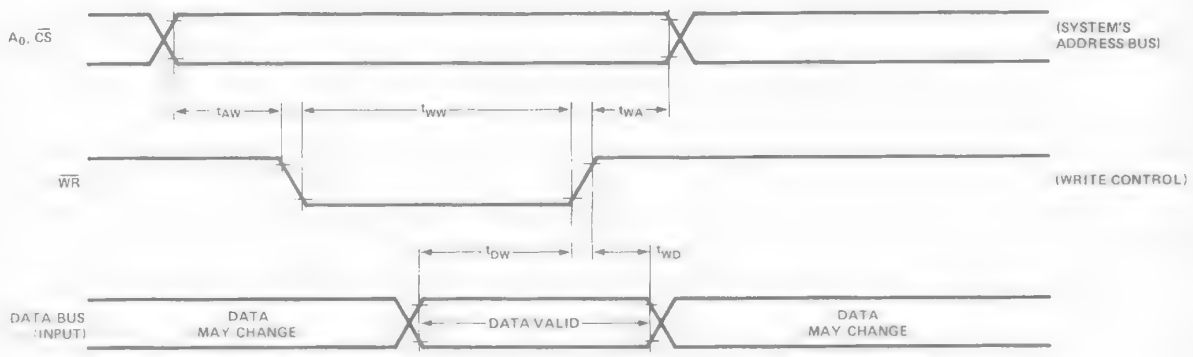
WAVEFORMS

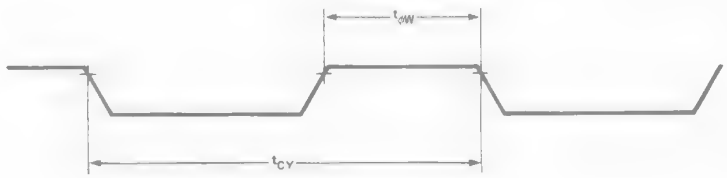
READ OPERATION



WRITE OPERATION



CLOCK INPUT



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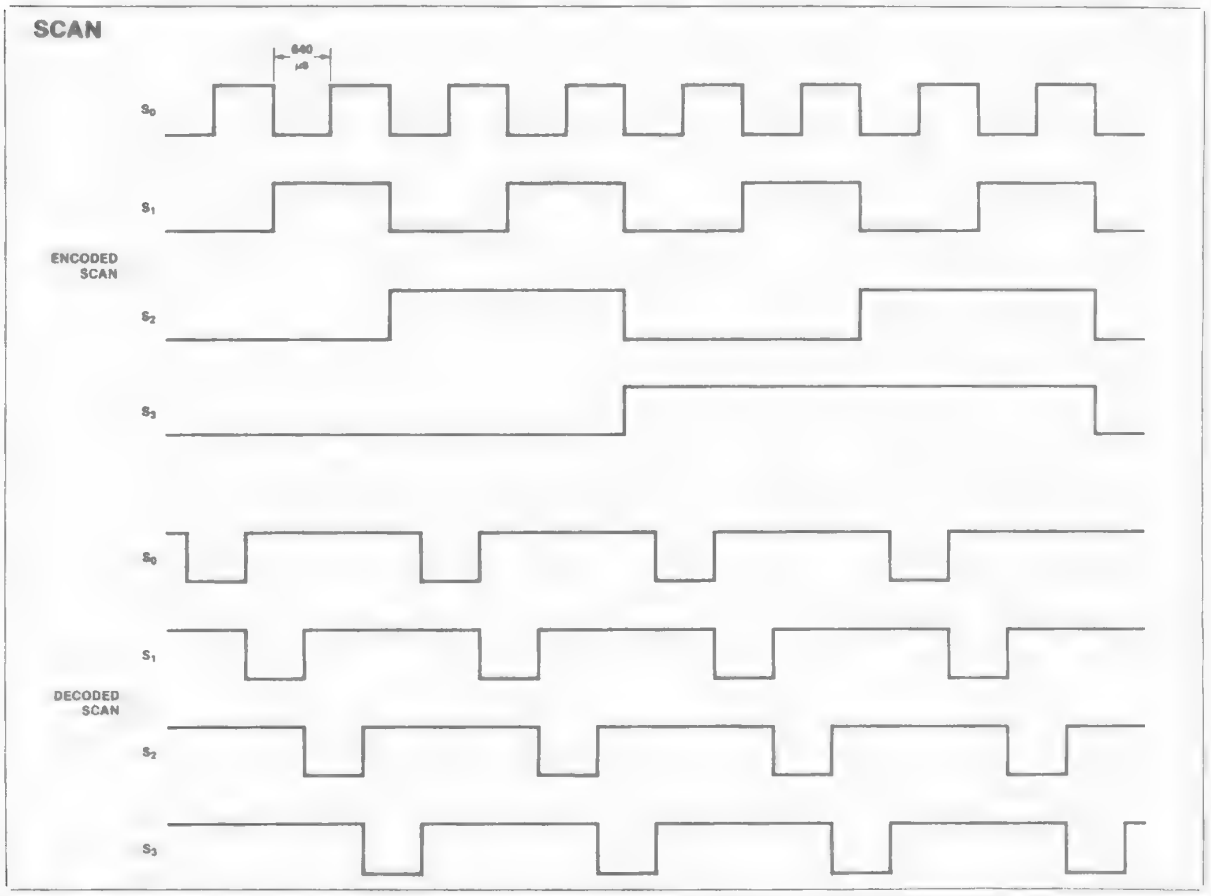
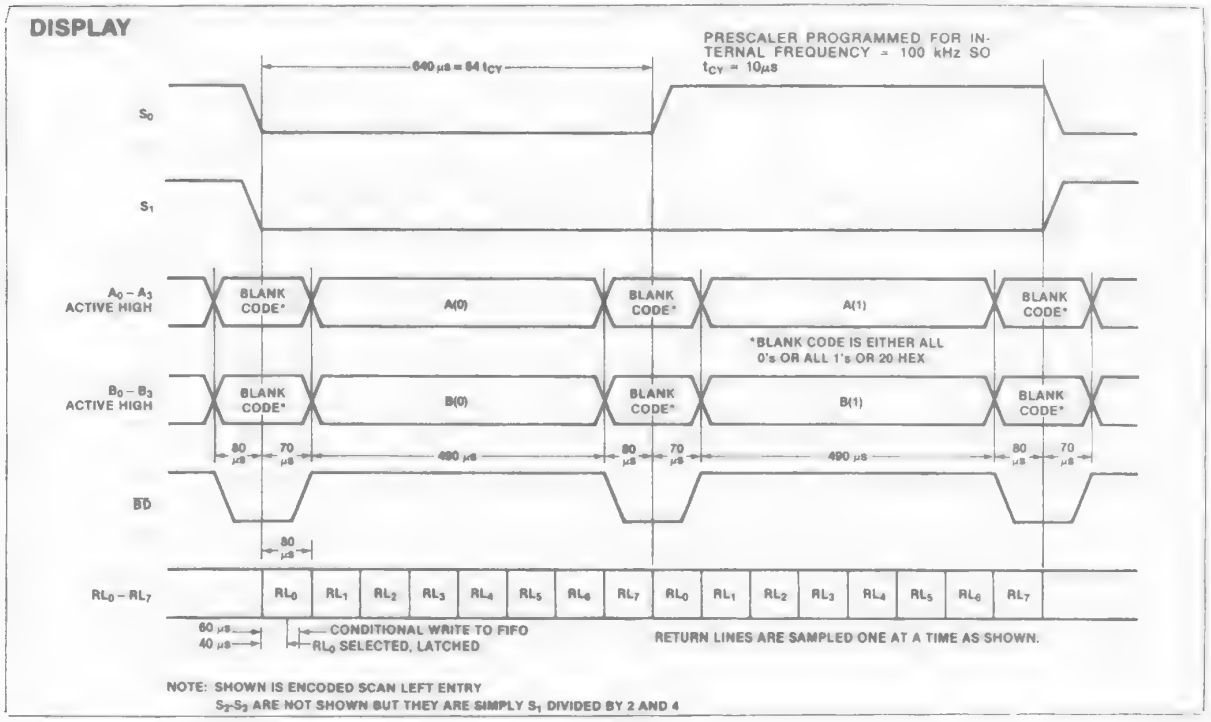
WAVEFORMS (Continued)





NOTE: SHOWN IS ENCODED SCAN LEFT ENTRY
S_2-S_3 ARE NOT SHOWN BUT THEY ARE SIMPLY S_1 DIVIDED BY 2 AND 4

AFN-00742B

PRELIMINARY

8291A
GPIB TALKER/LISTENER

- Designed to Interface Microprocessors (e.g., 8048/49, 8051, 8080/85, 8086/88) to an IEEE Standard 488 Digital Interface Bus
- Programmable Data Transfer Rate
- Complete Source and Acceptor Handshake
- Complete Talker and Listener Functions with Extended Addressing
- Service Request, Parallel Poll, Device Clear, Device Trigger, Remote/Local Functions
- Selectable Interrupts
- On-Chip Primary and Secondary Address Recognition
- Automatic Handling of Addressing and Handshake Protocol
- Provision for Software Implementation of Additional Features
- 1–8 MHz Clock Range
- 16 Registers (8 Read, 8 Write), 2 for Data Transfer, the Rest for Interface Function Control, Status, etc.
- Directly Interfaces to External Non-Inverting Transceivers for Connection to the GPIB
- Provides Three Addressing Modes, Allowing the Chip to be Addressed Either as a Major or a Minor Talker/Listener with Primary or Secondary Addressing
- DMA Handshake Provision Allows for Bus Transfers without CPU Intervention
- Trigger Output Pin
- On-Chip EOS (End of Sequence) Message Recognition Facilitates Handling of Multi-Byte Transfers

The 8291A is an enhanced version of the 8291 GPIB Talker/Listener designed to interface microprocessors to an IEEE Standard 488 Instrumentation Interface Bus. It implements all of the Standard's interface functions except for the controller. The controller function can be added with the 8292 GPIB Controller, and the 8293 GPIB Transceiver performs the electrical interface for Talker/Listener and Talker/Listener/Controller configurations.

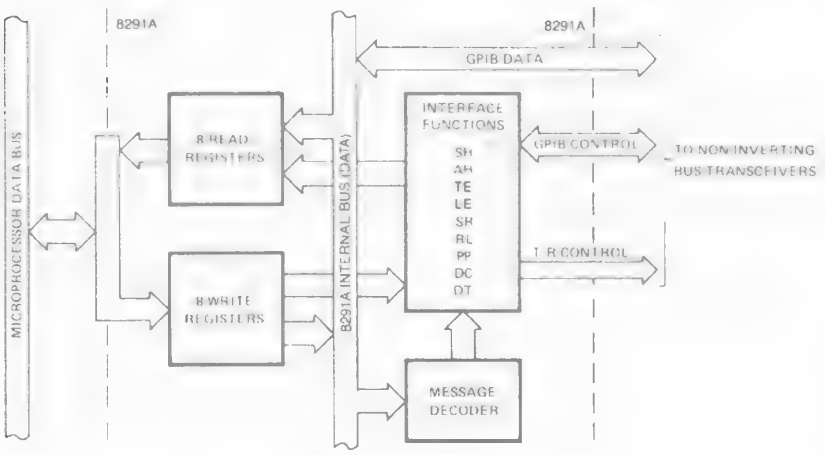


Figure 1. Block Diagram

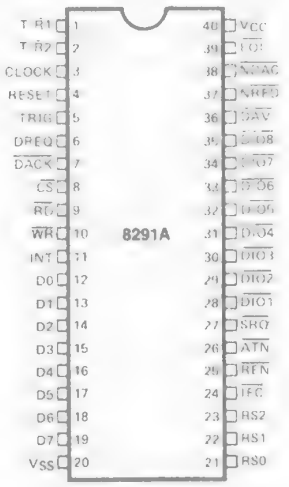


Figure 2. Pin Configuration

8291A FEATURES AND IMPROVEMENTS

The 8291A is an improved design of the 8291 GPIB Talker/Listener. Most of the functions are identical to the 8291, and the pin configuration is unchanged.

The 8291A offers the following improvements to the 8291:

1. $\overline{EOI}$ is active with the data as a ninth data bit rather than as a control bit. This is to comply with some additions to the 1975 IEEE-488 Standard incorporated in the 1978 Standard.

2. The BO interrupt is not asserted until RFD is true. If the Controller asserts $\overline{ATN}$ synchronously, the data is guaranteed to be transmitted. If the Controller asserts $\overline{ATN}$ asynchronously, the SH (Source Handshake) will return to SIDS (Source Idle State), and the output data will be cleared. The, if $\overline{ATN}$ is released while the 8291A is addressed to talk, a new BO interrupt will be generated. This change fixes 8291 problems which caused data to be lost or repeated and a problem with the RQS bit (sometimes cannot be asserted while talking).

3. LLOC and REMC interrupts are setting flipflops rather than toggling flipflops in the interrupt backup register. This ensures that the CPU knows that these state changes have occurred. The actual state can be determined by checking the LLO and REM status bits in the upper nibble of the Interrupt Status 2 Register.

4. DREQ is cleared by $\overline{DACK}$ ($\overline{RD}$ + $\overline{WR}$). DREQ on the 8291 was cleared only by $\overline{DACK}$ which is not compatible with the 8089 I/O Processor.

5. The INT bit in Interrupt Status 2 Register is duplicated in bit 7 of the Address 0 Register. If software polling is used to check for an interrupt, INT in the Address 0 Register should be polled rather than the Interrupt Status 2 Register. This ensures that no interrupts are lost due to asynchronous status reads and interrupts.

6. The 8291A's Send $\overline{EOI}$ Auxiliary Command works on any byte including the first byte of a message. The 8291 did not assert $\overline{EOI}$ after this command for a one byte message nor on two consecutive bytes.

7. To avoid confusion between holdoff on DAV versus RFD if a device is readdressed from a talker to a listener role or vice-versa during a holdoff, the "Holdoff on Source Handshake" has been eliminated. Only "Holdoff on Acceptor Handshake" is available.

8. The rsv local message is cleared automatically upon exit from SPAS if (APRS.STRS.SPAS) occurred. The automatic resetting of the bit after the serial poll is complete simplifies the service request software.

9. The SPASC interrupt on the 8291 has been replaced by the SPC (Serial Poll Complete) interrupt on the 8291A. SPC interrupt is set on exit from SPAS if APRS.STRS.SPAS occurred, indicating that the controller has read the bus status byte after the 8291A requested service. The SPASC interrupt was ambiguous because a controller could enter SPAS and exit SPAS generating two SPASC interrupts without reading the serial poll status byte. The SPC interrupt also simplifies the CPU's software by eliminating the interrupt when the serial poll is half way done.

10. The rtl Auxiliary Command in the 8291 has been replaced by Set and Clear rtl Commands in the 8291A. Using the new commands, the CPU has the flexibility to extend the length of local mode or leave it as a short pulse as in the 8291.

11. A holdoff RFD on GET, SDC, and DCL feature has been added to prevent additional bus activity while the CPU is responding to any of these commands. The feature is enabled by a new bit (B_4) in the Auxiliary Register B.

12. On the 8291, BO could cease to occur upon $\overline{IFC}$ going false if $\overline{IFC}$ occurred asynchronously. On the 8291A, BO continues to occur after $\overline{IFC}$ has gone false even if it arrived asynchronously.

13. User's software can distinguish between the 8291 and the 8291A as follows:

    a) pon (00H to register 5)
    b) RESET (02H to register 5)
    c) Read Interrupt Status 1 Register. If BO interrupt is set, the device is the 8291. If BO is clear, it is the 8291A.

    This can be used to set a flag in the user's software which will permit special routines to be executed for each device. It could be included as part of a normal initialization procedure as the first step after a chip reset.

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
D_0–D_7	12–19	I/O	**Data Bus Port:** To be connected to microprocessor data bus.
RS_0–RS_2	21–23	I	**Register Select:** Inputs, to be connected to three non-multiplexed microprocessor address bus lines. Select which of the 8 internal read (write) registers will be read from (written into) with the execution of $\overline{RD}$ ($\overline{WR}$.)
$\overline{CS}$	8	I	**Chip Select:** When low, enables reading from or writing into the register selected by RS_0–RS_2.
$\overline{RD}$	9	I	**Read Strobe:** When low with $\overline{CS}$ or $\overline{DACK}$ low, selected register contents are read.
$\overline{WR}$	10	I	**Write Strobe:** When low with $\overline{CS}$ or $\overline{DACK}$ low, data is written into the selected register.
INT ($\overline{INT}$)	11	O	**Interrupt Request:** To the microprocessor, set high for request and cleared when the appropriate register is accessed by the CPU. May be software configured to be active low.
DREQ	6	O	**DMA Request:** Normally low, set high to indicate byte output or byte input in DMA mode; reset by $\overline{DACK}$.
$\overline{DACK}$	7	I	**DMA Acknowledge:** When low, resets DREQ and selects data in/data out register for DMA data transfer (actual transfer done by $\overline{RD}$/$\overline{WR}$ pulse). Must be high if DMA is not used.
TRIG	5	O	**Trigger Output:** Normally low; generates a triggering pulse with 1 μsec min. width in response to the GET bus command or Trigger auxillary command.
CLOCK	3	I	**External Clock:** Input, used only for T_1 delay generator. May be any speed in 1–8 MHz range.
RESET	4	I	**Reset Input:** When high, forces the device into an "idle" (initialization) mode. The device will remain at "idle" until released by the microprocessor, with the "Immediate Execute pon" local message.
$\overline{DIO_1}$–$\overline{DIO_8}$	28–35	I/O	**8-Bit GPIB Data Port:** Used for bidirectional data byte transfer between 8291A and GPIB via non-inverting external line transceivers.
$\overline{DAV}$	36	I/O	**Data Valid:** GPIB handshake control line. Indicates the availability and validity of information on the $\overline{DIO_1}$–$\overline{DIO_8}$ and $\overline{EOI}$ lines.
$\overline{NRFD}$	37	I/O	**Not Ready for Data:** GPIB handshake control line. Indicates the condition of readiness of device(s) connected to the bus to accept data.
$\overline{NDAC}$	38	I/O	**Not Data Accepted:** GPIB handshake control line. Indicates the condition of acceptance of data by the device(s) connected to the bus.
$\overline{ATN}$	26	I	**Attention:** GPIB command line. Specifies how data on $\overline{DIO}$ lines are to be interpreted.
$\overline{IFC}$	24	I	**Interface Clear:** GPIB command line. Places the interface functions in a known quiescent state.
$\overline{SRQ}$	27	O	**Service Request:** GPIB command line. Indicates the need for attention and requests an interruption of the current sequence of events on the GPIB.
$\overline{REN}$	25	I	**Remote Enable:** GPIB command line. Selects (in conjunction with other messages) remote or local control of the device.
$\overline{EOI}$	39	I/O	**End or Identify:** GPIB command line. Indicates the end of a multiple byte transfer sequence or, in conjunction with ATN, addresses the device during a polling sequence.

Table 1. Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
T/$\overline{R1}$	1	O	**External Transceivers Control Line:** Set high to indicate output data/signals on the $\overline{DIO_1}$–$\overline{DIO_8}$ and $\overline{DAV}$ lines and input signals on the $\overline{NRFD}$ and $\overline{NDAC}$ lines (active source handshake). Set low to indicate input data/signals on the $\overline{DIO_1}$–$\overline{DIO_8}$ and $\overline{DAV}$ lines and output signals on the $\overline{NRFD}$ and $\overline{NDAC}$ lines (active acceptor handshake).
T/$\overline{R2}$	2	O	**External Transceivers Control Line:** Set to indicate output signals on the $\overline{EOI}$ line. Set low to indicate expected input signal on the $\overline{EOI}$ line during parallel poll.
V_{CC}	40	P.S.	**Positive Power Supply:** (5V ±10%).
GND	20	P.S.	**Circuit Ground Potential.**

NOTE:
All signals on the 8291A pins are specified with positive logic. However, IEEE 488 specifies negative logic on its 16 signal lines. Thus, the data is inverted once from D_0–D_7 to $\overline{DIO_0}$–$\overline{DIO_8}$ and non-inverting bus transceivers should be used.

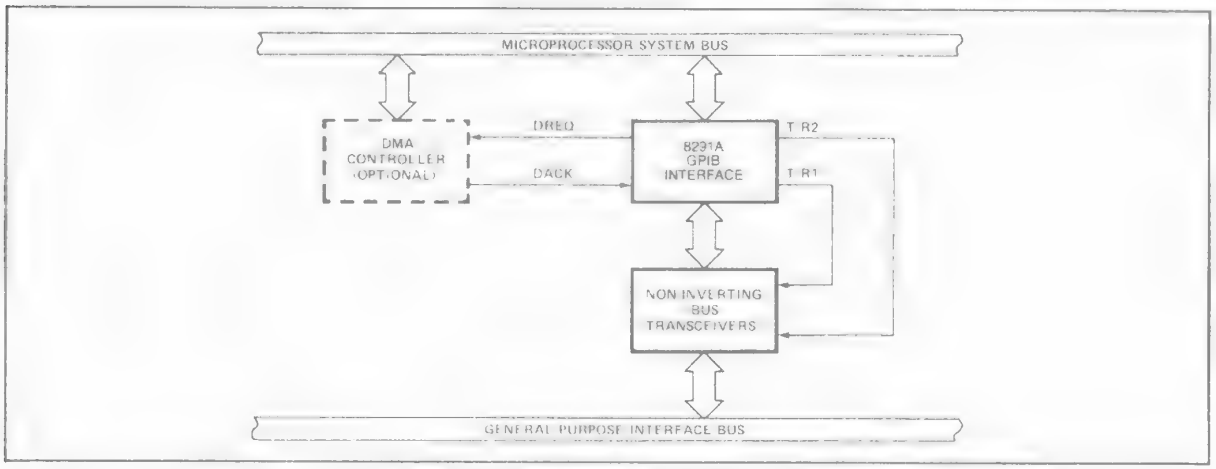


Figure 3. 8291A System Diagram

THE GENERAL PURPOSE INTERFACE BUS (GPIB)

The General Purpose Interface Bus (GPIB) is defined in the IEEE Standard 488-1978 "Digital Interface for Programmable Instrumentation." Although a knowledge of this standard is assumed, Figure 4 provides the bus structure for quick reference. Also, Tables 2 and 3 reference the interface state mnemonics and the interface messages respectively. Modified state diagrams for the 8291A are presented in Appendix A.

General Description

The 8291A is a microprocessor-controlled device designed to interface microprocessors, e.g., 8048/49, 8051, 8080/85, 8086/88 to the GPIB. It implements all of the interface functions defined in the IEEE-488 Standard except for the controller function. If an implementation of the Standard's Controller is desired, it can be connected with an Intel® 8292 to form a complete interface.

The 8291A handles communication between a microprocessor-controlled device and the GPIB. Its capabilities include data transfer, handshake protocol, talker/listener addressing procedures, device clearing and triggering, service request, and both serial and parallel polling. In most procedures, it does not disturb the microprocessor unless a byte has arrived (input buffer full) or has to be sent out (output buffer empty).

The 8291A architecture includes 16 registers. Eight of these registers may be written into by the microprocessor. The other eight registers may be read by the microprocessor. One each of these read and

write registers is for direct data transfers. The rest of the write registers control the various features of the chip, while the rest of the read registers provide the microprocessor with a monitor of GPIB states, various bus conditions, and device conditions.

GPIB Addressing

Each device connected to the GPIB must have at least one address whereby the controller device in charge of the bus can configure it to talk, listen, or send status. An 8291A implementation of the GPIB offers the user three alternative addressing modes for which the device can be initialized for each application. The first of these modes allows for the device to have two separate primary addresses. The second mode allows the user to implement a single talker/listener with a two byte address (primary address + secondary address). The third mode again allows for two distinct addresses but in this instance, they can each have a ten-bit address (5 low-order bits of each of two bytes). However, this mode requires that the secondary addresses be passed to the microprocessor for verification. These three addressing schemes are described in more detail in the discussion of the Address Registers.

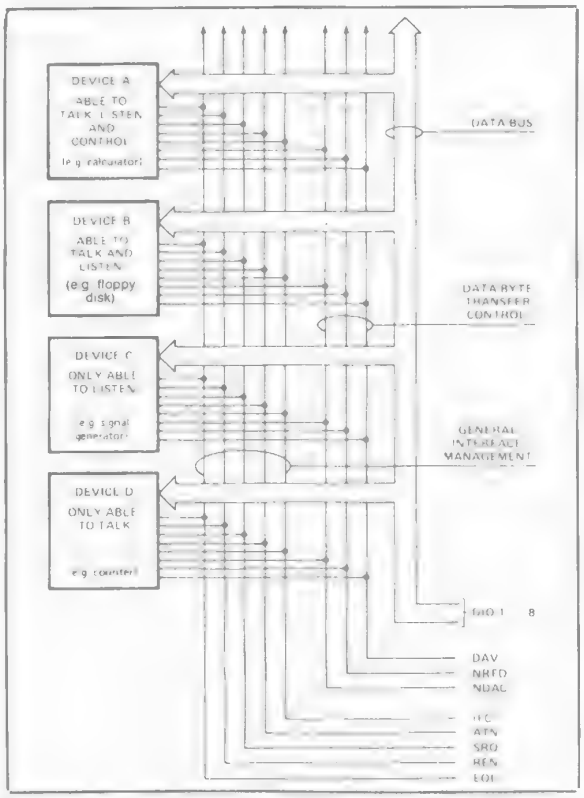


Figure 4. Interface Capabilities and Bus Structure

Table 2. IEEE 488 Interface State Mnemonics

Mnemonic	State Represented
ACDS	Accept Data State
ACRS	Acceptor Ready State
AIDS	Acceptor Idle State
ANRS	Acceptor Not Ready State
APRS	Affirmative Poll Response State
AWNS	Acceptor Wait for New Cycle State
CACS	Controller Active State *
CADS	Controller Addressed State *
CAWS	Controller Active Wait State *
CIDS	Controller Idle State *
CPPS	Controller Parallel Poll State *
CPWS	Controller Parallel Poll Wait State *
CSBS	Controller Standby State *
CSNS	Controller Service Not Requested State *
CSRS	Controller Service Requested State *
CSWS	Controller Synchronous Wait State *
CTRS	Controller Transfer State *
DCAS	Device Clear Active State
DCIS	Device Clear Idle State
DTAS	Device Trigger Active State
DTIS	Device Trigger Idle State
LACS	Listener Active State
LADS	Listener Addressed State
LIDS	Listener Idle State
LOCS	Local State
LPAS	Listener Primary Addressed State
LPIS	Listener Primary Idle State
LWLS	Local With Lockout State
NPRS	Negative Poll Response State
PACS	Parallel Poll Addressed to Configure State
PPAS	Parallel Poll Active State
PPIS	Parallel Poll Idle State
PPSS	Parallel Poll Standby State
PUCS	Parallel Poll Unaddressed to Configure State
REMS	Remote State
RWLS	Remote With Lockout State
SACS	System Control Active State
SDYS	Source Delay State
SGNS	Source Generate State
SIAS	System Control Interface Clear Active State
SIDS	Source Idle State
SIIS	System Control Interface Clear Idle State
SINS	System Control Interface Clear Not Active State
SIWS	Source Idle Wait State
SNAS	System Control Not Active State
SPAS	Serial Poll Active State
SPIS	Serial Poll Idle State
SPMS	Serial Poll Mode State
SRAS	System Control Remote Enable Active State
SRIS	System Control Remote Enable Idle State
SRNS	System Control Remote Enable Not Active State
SRQS	Service Request State
STRS	Source Transfer State
SWNS	Source Wait for New Cycle State
TACS	Talker Active State
TADS	Talker Addressed State
TIDS	Talker Idle State
TPIS	Talker Primary Idle State

*The Controller function is implemented on the Intel® 8292.

Table 3. IEEE 488 Interface Message Reference List

Mnemonic	Message	Interface Function(s)
LOCAL MESSAGES RECEIVED (By Interface Functions)		
[1]gts	go to standby	C
ist	individual status	PP
lon	listen only	L, LE
lpe	local poll enable	PP
nba	new byte available	SH
pon	power on	SH,AH,T,TE,L,LE,SR,RL,PP,C
rdy	ready	AH
[1]rpp	request parallel poll	C
[1]rsc	request system control	C
rsv	request service	SR
rtl	return to local	RL
[1]sic	send interface clear	C
[1]sre	send remote enable	C
[1]tca	take control asynchronously	C
[1]tcs	take control synchronously	AH, C
ton	talk only	T, TE
REMOTE MESSAGES RECEIVED		
ATN	Attention	SH,AH,T,TE,L,LE,PP,C
DAB	Data Byte	(Via L, LE)
DAC	Data Accepted	SH
DAV	Data Valid	AH
DCL	Device Clear	DC
END	End	(via L, LE)
GET	Group Execute Trigger	DT
GTL	Go to Local	RL
IDY	Identify	L,LE,PP
IFC	Interface Clear	T,TE,L,LE,C
LLO	Local Lockout	RL
MLA	My Listen Address	L,LE,RL,T,TE
MSA	My Secondary Address	TE,LE,RL
MTA	My Talk Address	T,TE,L,LE
OSA	Other Secondary Address	TE
OTA	Other Talk Address	T, TE
PCG	Primary Command Group	TE,LE,PP
[2]PPC	Parallel Poll Configure	PP
[2][PPD]	Parallel Poll Disable	PP
[2][PPE]	Parallel Poll Enable	PP
[1]PPR_N	Parallel Poll Response N	(via C)
[2]PPU	Parallel Poll Unconfigure	PP
REN	Remote Enable	RL
RFD	Ready for Data	SH
RQS	Request Service	(via L, LE)
[SDC]	Select Device Clear	DC
SPD	Serial Poll Disable	T, TE
SPE	Serial Poll Enable	T, TE
[1]SQR	Service Request	(via C)
STB	Status Byte	(via L, LE)
[1]TCT or [TCT]	Take Control	C
UNL	Unlisten	L, LE

NOTE:
1. These messages are handled only by Intel's 8292.
2. Undefined commands which may be passed to the microprocessor.

Table 3. (Cont'd)
IEEE 488 Interface Message Reference List

Mnemonic	Message	[3]Interface Function(s)
REMOTE MESSAGES SENT		
ATN	Attention	C
DAB	Data Byte	(via T, TE)
DAC	Data Accepted	AH
DAV	Data Valid	SH
DCL	Device Clear	(via C)
END	End	(via T)
GET	Group Execute Trigger	(via C)
GTL	Go to Local	(via C)
IDY	Identify	C
IFC	Interface Clear	C
LLO	Local Lockout	(via C)
MLA or [MLA]	My Listen Address	(via C)
MSA or [MSA]	My Secondary Address	(via C)
MTA or [MTA]	My Talk Address	(via C)
OSA	Other Secondary Address	(via C)
OTA	Other Talk Address	(via C)
PCG	Primary Command Group	(via C)
PPC	Parallel Poll Configure	(via C)
[PPD]	Parallel Poll Disable	(via C)
[PPE]	Parallel Poll Enable	(via C)
PPR_N	Parallel Poll Response N	PP
PPU	Parallel Poll Unconfigure	(via C)
REN	Remote Enable	C
RFD	Ready for Data	AH
RQS	Request Service	T, TE
SDC]	Selected Device Clear	(via C)
SPD	Serial Poll Disable	(via C)
SPE	Serial Poll Enable	(via C)
SRQ	Service Request	SR
STB	Status Byte	(via T, TE)
TCT	Take Control	(via C)
UNL	Unlisten	(via C)

NOTE:
3. All Controller messages must be sent via Intel's 8292.

8291A Registers

A bit-by-bit map of the 16 registers on the 8291A is presented in Figure 5. A more detailed explanation of each of these registers and their functions follows. The access of these registers by the microprocessor is accomplished by using the $\overline{CS}$, $\overline{RD}$, $\overline{WR}$, and RS_0-RS_2 pins.

Register	$\overline{CS}$	$\overline{RD}$	$\overline{WR}$	RS_0-RS_2
All Read Registers	0	0	1	CCC
All Write Registers	0	1	0	CCC
High Impedance	1	d	d	ddd

Data Registers

DI7	DI6	DI5	DI4	DI3	DI2	DI1	DI0

DATA-IN REGISTER (0R)

DO7	DO6	DO5	DO4	DO3	DO2	DO1	DO0

DATA-OUT REGISTER (0W)

The Data-In Register is used to move data from the GPIB to the microprocessor or to memory when the 8291A is addressed to listen. Incoming information is separately latched by this register, and its contents are not destroyed by a write to the data-out

register. The RFD (Ready for Data) message is held false until the byte is removed from the data in register, either by the microprocessor or by DMA. The 8291A then completes the handshake automatically. In RFD holdoff mode (see Auxiliary Register A), the handshake is not finished until a command is sent telling the 8291A to release the holdoff. In this way, the same byte may be read seveal times, or an over anxious talker may be held off until all available data has been processed.

When the 8291A is addressed to talk, it uses the data-out register to move data onto the GPIB. After the BO interrupt is received and a byte is written to this register, the 8291A initiates and completes the handshake while sending the byte out over the bus. In the BO interrupt disable mode, the user should wait until BO is active before writing to the register. (In the DMA mode, this will happen automatically.) A read of the Data-In Register does not destroy the information in the Data-Out Register.

Interrupt Registers

CPT	APT	GET	END	DEC	ERR	BO	BI

INTERRUPT STATUS 1 (1R)

INT	SPAS	LLO	REM	SPC	LLOC	REMC	ADSC

INTERRUPT STATUS 2 (2R)

CPT	APT	GET	END	DEC	ERR	BO	BI

INTERRUPT ENABLE 1 (1W)

0	0	DMAO	DMAI	SPC	LLOC	REMC	ADSC

INTERRUPT ENABLE 2 (2W)

INT	DT0	DL0	AD5-0	AD4-0	AD3-0	AD2-0	AD1-0

ADDRESS 0 REGISTER

Figure 5. 8291A Registers

READ REGISTERS								REGISTER SELECT CODE RS2	RS1	RS0	WRITE REGISTERS							
DI7	DI6	DI5	DI4	DI3	DI2	DI1	DI0	0	0	0	DO7	DO6	DO5	DO4	DO3	DO2	DO1	DO0
DATA IN											DATA OUT							
CPT	APT	GET	END	DEC	ERR	BO	BI	0	0	1	CPT	APT	GET	END	DEC	ERR	BO	BI
INTERRUPT STATUS 1											INTERRUPT ENABLE 1							
INT	SPAS	LLO	REM	SPC	LLOC	REMC	ADSC	0	1	0	0	0	DMAO	DMAI	SPC	LLOC	REMC	ADSC
INTERRUPT STATUS 2											INTERRUPT ENABLE 2							
S8	SRQS	S6	S5	S4	S3	S2	S1	0	1	1	S8	rsv	S6	S5	S4	S3	S2	S1
SERIAL POLL STATUS											SERIAL POLL MODE							
ton	lon	EOI	LPAS	TPAS	LA	TA	MJMN	1	0	0	TO	LO	0	0	0	0	ADM1	ADM0
ADDRESS STATUS											ADDRESS MODE							
CPT7	CPT6	CPT5	CPT4	CPT3	CPT2	CPT1	CPT0	1	0	1	CNT2	CNT1	CNT0	COM4	COM3	COM2	COM1	COM0
COMMAND PASS THROUGH											AUX MODE							
INT	DT0	DL0	AD5-0	AD4-0	AD3-0	AD2-0	AD1-0	1	1	0	ARS	DT	DL	AD5	AD4	AD3	AD2	AD1
ADDRESS 0											ADDRESS 0/1							
X	DT1	DL1	AD5-1	AD4-1	AD3-1	AD2-1	AD1-1	1	1	1	EC7	EC6	EC5	EC4	EC3	EC2	EC1	EC0
ADDRESS 1											EOS							

AFN-00229B

The 8291A can be configured to generate an interrupt to the microprocessor upon the occurrence of any of 12 conditions or events on the GPIB. Upon receipt of an interrupt, the microprocessor must read the Interrupt Status Registers to determine which event has occurred, and then execute the appropriate service routine (if necessary). Each of the 12 interrupt status bits has a matching enable bit in the interrupt enable registers. These enable bits are used to select the events that will cause the INT pin to be asserted. Writing a logic "1" into any of these bits enables the corresponding interrupt status bits to generate an interrupt. Bits in the Interrupt Status Registers are set regardless of the states of the enable bits. The Interrupt Status Registers are then cleared upon being read or when a local pon (power-on) message is executed. If an event occurs while one of the Interrupt Status Registers is being read, the event is held until after its register is cleared and then placed in the register.

The mnemonics for each of the bits in these registers and a brief description of their respective functions appears in Table 4. This tables also indicates how each of the interrupt bits is set.

NOTE: The INT bit in the Address 0 Register is a duplicate of the INT bit in the Interrupt Status 2 Register. It is only a status bit. It does not generate interrupts and thus does not have a corresponding enable bit.

The BO and BI interrupts enable the user to perform data transfer cycles. BO indicates that a data byte should be written to the Data Out Register. It is set by TACS · (SWNS + SGNS) · RFD. It is reset when the data byte is written, ATN is asserted, or the 8291A exits TACS. Data should never be written to the Data Out Register before BO is set. Similarly, BI is set when an input byte is accepted into the 8291A and reset when the microprocessor reads the Data In Register. BO and BI are also reset by pon (power-on local message) and by a read of the Interrupt

Table 4. Interrupt Bits

Indicates Undefined Commands	CPT	An undefined command has been received.
Set by (TPAS + LPAS)•SCG•ACDS•MODE 3	APT	A secondary address must be passed through to the microprocessor for recognition.
Set by DTAS	GET	A group execute trigger has occurred.
Set by (EOS + EOI)•LACS	END	An EOS or EOI message has been received.
Set by DCAS	DEC	Device Clear Active State has occurred.
Set by TACS•nba•DAC•RFD	ERR	Interface error has occurred; no listeners are active.
TACS•(SWNS + SGNS)	BO	A byte should be output.
Set by LACS•ACDS	BI	A byte has been input.
Shows status of the INT pin	INT	These are status only. They will not generate interrupts, nor do they have corresponding mask bits.
The device has been enabled for a serial poll	SPAS	
The device is in local lock out state. (LWLS+RWLS)	LLO	
The device is in a remote state. (REMS+RWLS)	REM	
SPAS → $\overline{\text{SPAS}}$ if APRS:STRS:SPAS was true	SPC	Serial Poll Complete interrupt.
LLO ⇄ NO LLO	LLOC	Local lock out change interrupt.
Remote ⇄ Local	REMC	Remote/Local change interrupt.
Addressed ⇄ Unaddressed	ADSC	Address status change interrupt.[1]

NOTE: [1]In ton (talk-only) and lon (listen-only) modes, no ADSC interrupt is generated.

Status 1 Register. However, if it is so desired, data transfer cycles may be performed without reading the Interrupt Status 1 Register if all interrupts except for BO or BI are disabled; BO and BI will automatically reset after each byte is transferred.

If the 8291A is used in the interrupt mode, the INT and DREQ pins can be dedicated to data input and output interrupts respectively by enabling BI and DMAO, provided that no other interrupts are enabled. This eliminates the need to read the interrupt status registers if a byte is received or transmitted.

The ERR bit is set to indicate the bus error condition when the 8291A is an active talker and tries to send a byte to the GPIB, but there are no active listeners (e.g., all devices on the GPIB are in AIDS). The logical equivalent of (nba · TACS · DAC · RFD) will set this bit.

The DEC bit is set whenever DCAS has occurred. The user must define a known state to which all device functions will return in DCAS. Typically this state will be a power-on state. However, the state of the device functions at DCAS is at the designer's discretion. It should be noted that DCAS has no effect on the interface functions which are returned to a known state by the IFC (interface clear) message or the pon local message.

The END interrupt bit may be used by the microprocessor to detect that a multi-byte transfer has been completed. The bit will be set when the 8291A is an active listener (LACS) and either EOS (provided the End on EOS Received feature is enabled in the Auxiliary Register A) or EOI is received. EOS will generate an interrupt when the byte in the Data In Register matches the byte in the EOS register. Otherwise the interrupt will be generated when a true input is detected on EOI.

The GET interrupt bit is used by the microprocessor to detect that DTAS has occurred. It is set by the 8291A when the GET message is received while it is addressed to listen. The TRIG output pin of the 8291A fires when the GET message is received. Thus, the basic operation of device trigger may be started without microprocessor software intervention.

The APT interrupt bit indicates to the processor that a secondary address is available in the CPT register for validation. This interrupt will only occur if Mode 3 addressing is in effect. (Refer to the section on addressing.) In Mode 2, secondary addresses will be recognized automatically on the 8291A. They will be ignored in Mode 1.

The CPT interrupt bit flags the occurrence of an undefined command and of all secondary commands following an undefined command. The Command Pass Through feature is enabled by the B0 bit of Auxiliary Register B. Any message not decoded by the 8291A (not included in the state diagrams in Appendix B) becomes an undefined command. Note that any addressed command is automatically ignored when the 8291A is not addressed.

Undefined commands are read by the CPU from the Command Pass Through register of the 8291A. This register reflects the logic levels present on the data lines at the time it is read. If the CPT feature is enabled, the 8291A will hold off the handshake until this register is read.

An especially useful feature of the 8291A is its ability to generate interrupts from state transitions in the interface functions. In particular, the lower 3 bits of the Interrupt Status 2 Register, if enabled by the corresponding enable bits, will cause an interrupt upon changes in the following states as defined in the IEEE 488 Standard.

Bit 0	ADSC	change in LIDS or TIDS or MJMN
Bit 1	REMC	change in LOCS or REMS
Bit 2	LLOC	change in LWLS or RWLS

The upper 4 bits of the Interrupt Status 2 Register are available to the processor as status bits. Thus, if one of the bits 1 and 2 generates an interrupt indicating a state change has taken place, the corresponding status bit (bits 4 and 5) may be read to determine what the new state is. To determine the nature of a change in addressed status (bit 0) the Address Status Register is available to be read. The SPC interrupt (bit 3 in Interrupt Status 2) is set upon exit from SPAS if APRS:STRS:SPAS occurred which indicates that the GPIB controller has read the bus serial poll status byte after the 8291A requested service (asserted SRQ). The SPC interrupt occurs once after the controller reads the status byte if service was requested.

The controller may read the status byte later, and the byte will contain the last status the 8291A's CPU wrote to the Serial Poll Mode Register, but the SRQS bit will not be set and no interrupt will be generated. Finally, bit 7 monitors the state of the 8291A INT pin. Logically, it is an OR of all enabled interrupt status bits. One should note that bits 4–7 of the Interrupt Status 2 Register do not generate interrupts, but are available only to be read as status bits by the processor. Bit 7 in Interrupt Status 2 is duplicated in Address 0 Register, and the latter should be used when polling for interrupts to avoid losing one of the interrupts in Interrupt Status 2 Register.

Bits 4 and 5 (DMAI, DMAO) of the Interrupt Mask 2 Register are available to enable direct data transfers between memory and the GPIB; DMAI (DMA in) enables the DREQ (DMA request) pin of the 8291A to be asserted upon the occurrence of BI. Similarly, DMAO (DMA out) enables the DREQ pin to be asserted upon the occurrence of BO. One might note that the DREQ pin may be used as a second interrupt output pin, monitoring BI and/or BO and enabled by DMAI and DMAO. One should note that the DREQ pin is not affected by a read of the Interrupt Status 1 Register. It is reset whenever a byte is written to the Data Out Register or read from the Data In Register.

To ensure that an interrupt status bit will not be cleared without being read, and will not remain uncleared after being read, the 8291A implements a special interrupt handling procedure. When an enabled interrupt bit is set in either of the Interrupt Status Registers, the input of the registers are blocked until the set bit is read and reset by the microprocessor. Thus, potential problems arise when interrupt status changes while the register is being blocked. However, the 8291A stores all new interrupts in a temporary register and transfers them to the appropriate Interrupt Status Register after the interrupt has been reset. This transfer takes place only if the corresponding bits were read as zeroes.

Serial Poll Registers

S8	SRQS	S6	S5	S4	S3	S2	S1

SERIAL POLL STATUS (3R)

S8	rsv	S6	S5	S4	S3	S2	S1

SERIAL POLL MODE (3W)

The Serial Poll Mode Register determines the status byte that the 8291A sends out on the GPIB data lines when it receives the SPE (Serial Poll Enable) message. Bit 6 of this register is reserved for the rsv (request service) local message. Setting this bit to 1 causes the 8291A to assert its $\overline{SRQ}$ line, indicating its need for attention from the controller-in-charge of the GPIB. The other bits of this register are available for sending status information over the GPIB. Sometime after the microprocessor initiates a request for service by setting bit 6, the controller of the GPIB sends the SPE message and then addresses the 8291A to talk. At this point, one byte of status is returned by the 8291A via the Serial Poll Mode Register. After the status byte is read by the controller, rsv is automatically cleared by the 8291A and an SPC interrupt is generated. The CPU may request service again by writing another byte to the Serial Poll Mode Register with the rsv bit set. If the controller performs a serial poll when the rsv bit is clear, the last status byte written will be read, but the $\overline{SRQ}$ line will not be driven by the 8291A and the SRQS bit will be clear in the status byte.

The Serial Poll Status Register is available for reading the status byte in the Serial Poll Mode Register. The processor may check the status of a request for service by polling bit 6 of this register, which corresponds to SRQS (Service Request State). When a Serial Poll is conducted and the controller-in-charge reads the status byte, the SRQS bit is cleared. The $\overline{SRQ}$ line and the rsv bit are tied together.

Address Registers

ton	lon	EOI	LPAS	TPAS	LA	TA	MJMN

ADDRESS STATUS (4R)

INT	DT0	DL0	AD5-0	AD4-0	AD3-0	AD2-0	AD1-0

ADDRESS 0 (6R)

X	DT1	DL1	AD5-1	AD4-1	AD3-1	AD2-1	AD1-1

ADDRESS 1 (7R)

TO	LO	0	0	0	0	ADM1	ADM0

ADDRESS MODE (4W)

ARS	DT	DL	AD5	AD4	AD3	AD2	AD1

ADDRESS 0/1 (6W)

The Address Mode Register is used to select one of the five modes of addressing available on the 8291A. It determines the way in which the 8291A uses the information in the Address 0 and Address 1 Registers.

—In Mode 1, the contents of the Address 0 Register constitute the "Major" talker/listener address while the Address 1 Register represents the "Minor" talker/listener address. In applications where only one address is needed, the major talker/listener is used, and the minor talker/listener should be disabled. Loading an address via the Address 0/1 Register into Address Registers 0 and 1 enables the major and minor talker/listener functions respectively.

—In Mode 2 the 8291A recognizes two sequential address bytes: a primary followed by a secondary. Both address bytes must be received in order to enable the device to talk or listen. In this manner, Mode 2 addressing implements the extended talker and listener functions as defined in IEEE-488.

To use Mode 2 addressing the primary address must be loaded into the Address 0 Register, and the Secondary Address is placed in the Address 1 Register. With both primary and secondary addresses residing on chip, the 8291A can handle all addressing sequences without processor intervention.

—In Mode 3, the 8291A handles addressing just as it does in Mode 1, except that each Major or Minor primary address must be followed by a secondary address. All secondary addresses must be verified by the microprocessor when Mode 3 is used. When the 8291A is in TPAS or LPAS (talker/listener primary addressed state), and it does not recognize the byte on the DIO lines, an APT interrupt is generated (see section on Interrupt Registers) and the byte is available in the CPT (Command Pass-Through) Register. As part of its interrupt service routine, the microprocessor must read the CPT Register and write one of the following responses to the Auxiliary Mode Register:

1. 07H implies a non-valid secondary address
2. 0FH implies a valid secondary address

Setting the TO bit generates the local ton (talk-only) message and sets the 8291A to a talk-only mode. This mode allows the device to operate as a talker in an interface system without a controller.

Setting the LO bit generates the local lon (listen-only) message and sets the 8291A to a listen-only mode. This mode allows the device to operate as a listener in an interface system without a controller. The above bits may also be used by a controller-in-charge to set itself up for remote command or data communication.

The mode of addressing implemented by the 8291A may be selected by writing one of the following bytes to the Address Mode Register.

Register Contents	Mode
10000000	Enable talk only mode (ton)
01000000	Enable listen only mode (lon)
11000000	The 8291 may talk to itself
00000001	Mode 1, (Primary-Primary)
00000010	Mode 2 (Primary-Secondary)
00000011	Mode 3 (Primary/APT-Primary/APT)

The Address Status Register contains information used by the microprocessor to handle its own addressing. This information includes status bits that monitor the address state of each talker/listener, "ton" and "lon" flags which indicate the talk and listen only states, and an EOI bit which, when set, signifies that the END message came with the last data byte. LPAS and TPAS indicate that the listener or talker primary address has been received. The microprocessor can use these bits when the secondary address is passed through to determine whether the 8291A is addressed to talk or listen. The LA (listener addressed) bit will be set when the 8291A is in LACS (Listener Active State) or in LADS (Listener Addressed State). Similarly, the TA (Talker Addressed bit) will be set to indicate TACS or TADS, but also to indicate SPAS (Serial Poll Active State). The MJMN bit is used to determine whether the information in the other bits applies to the Major or Minor talker/listener. It is set to "1" when the Minor talker/listener is addressed. It should be noted that only one talker/listener may be active at any one time. Thus, the MJMN bit will indicate which, if either, of the talker/listeners is addressed or active.

The Address 0/1 Register is used for specifying the device's addresses according to the format selected in the Address Mode Register. Five bit addresses may be loaded into the Address 0 and Address 1 Registers by writing into the Address 0/1 Register. The ARS bit is used to select which of these registers the other seven bits will be loaded into. The DT and DL bits may be used to disable the talker or listener function at the address signified by the other five

bits. When Mode 1 addressing is used and only one primary address is desired, *both* the talker and the listener should be disabled at the Minor address.

As an example of how the Address 0/1 Register might be used, consider an example where two primary addresses are needed in the device. The Major primary address will be selectable only as a talker and the Minor primary address will be selectable only as a listener. This configuration of the 8291A is formed by the following sequence of writes by the microprocessor.

Operation	$\overline{CS}$	$\overline{RD}$	$\overline{WR}$	Data	RS2-RS0
1. Select addressing Mode 1	0	1	0	00000001	100
2. Load major address into Address 0 Register with listener function disabled.	0	1	0	001AAAAA	110
3. Load minor address into Address 1 Register with talker function disabled.	0	1	0	110BBBBB	110

At this point, the addresses AAAAA and BBBBB are stored in the Address 0 and Address 1 Registers respectively, and are available to be read by the microprocessor. Thus, it is not necessary to store any address information elsewhere. Also, with the information stored in the Address 0 and Address 1 Registers, processor intervention is not required to recognize addressing by the controller. Only in Mode 3, where secondary addresses are passed through, must the processor intervene in the addressing sequence.

The Address 0 Register contains a copy of bit 7 of the Interrupt Status 2 Register (INT). This is to be used when polling for interrupts. Software should poll register 6 checking for INT (bit 7) to be set. When INT is set, the Interrupt Status Register should be read to determine which interrupt was received.

Command Pass Through Register

CPT7	CPT6	CPT5	CPT4	CPT3	CPT2	CPT1	CPT0

COMMAND PASS THROUGH (5R)

The Command Pass Through Register is used to transfer undefined 8-bit remote message codes from the GPIB to the microprocessor. When the CPT feature is enabled (bit B0 in Auxiliary Register B), any message not decoded by the 8291A becomes an undefined command. When Mode 3 addressing is used secondary addresses are also passed through the CPT Register. In either case, the 8291A will hold-off the handshake until the microprocessor reads this register and issues the VSCMD auxiliary command.

The CPT and APT interrupts flag the availablility of undefined commands and secondary addresses in the CPT Register. The details of these interrupts are explained in the section on Interrupt Registers.

An added feature of the 8291A is its ability to handle undefined secondary commands following undefined primaries. Thus, the number of available commands for future IEEE-488 definition is increased; one undefined primary command followed by a sequence of as many as 32 secondary commands can be processed. The IEEE-488 Standard does not permit users to define their own commands, but upgrades of the standard are thus provided for.

The recommended use of the 8291A's undefined command capabilities is for a controller-configured Parallel Poll. The PPC message is an undefined primary command typically followed by PPE, an undefined secondary command. For details on this procedure, refer to the section on Parallel Poll Protocol.

Auxiliary Mode Register

CNT2	CNT1	CNT0	COM4	COM3	COM2	COM1	COM0

AUX MODE (5W)

CNT0-2:CONTROL BITS
COM0-4:COMMAND BITS

The Auxiliary Mode Register contains a three-bit control field and a five-bit command field. It is used for several purposes on the 8291A:

1. To load "hidden" auxiliary registers on the 8291A.
2. To issue commands from the microprocessor to the 8291A.
3. To preset an internal counter used to generate T1, delay in the Source Handshake function, as defined in IEEE-488.

Table 5 summarizes how these tasks are performed with the Auxiliary Mode Register. Note that the three control bits determine how the five command bits are interpreted.

Table 5

CODE		COMMAND
CONTROL BITS	COMMAND BITS	
000	0CCCC	Execute auxiliary command CCCC
001	ODDDD	Preset internal counter to match external clock frequency of DDDD MHz (DDDD binary representation of 1 to 8 MHz)
100	DDDDD	Write DDDDD into auxiliary register A
101	DDDDD	Write DDDDD into auxiliary register B
011	$USP_3P_2P_1$	Enable/disable parallel poll either in response to remote messages (PPC followed by PPE or PPD) or as a local lpe message. (Enable if U = 0, disable if U = 1.)

AUXILIARY COMMANDS

Auxiliary commands are executed by the 8291A whenever 0000CCCC is written into the Auxiliary Mode Register, where CCCC is the 4-bit command code.

0000—Immediate Execute pon: This command resets the 8291A to a power up state (local pon message as defined in IEEE-488).
The following conditions constitute the power up state:
1. All talkers and listeners are disabled.
2. No interrupt status bits are set.

The 8291A is designed to power up in certain states as specified in the IEEE-488 state diagrams. Thus, the following states are in effect in the power up state: SIDS, AIDS, TIDS, LIDS, NPRS, LOCS, and PPIS.
The "0000" pon is an immediate execute command (a pon pulse). It is also used to release the "initialize" state generated by either an external reset pulse or the "0010" Chip Reset command.

0010—Chip Reset (Initialize): This command has the same effect as a pulse applied to the Reset pin. (Refer to the section on Reset Procedure.)

0011—Finish Handshake : This command finishes a handshake that was stopped because of a holdoff on RFD. (Refer to Auxiliary Register A.)

0100—Trigger: A "Group Execute Trigger" is forced by this command. It has the same effect as a GET command issued by the controller-in-charge of the GPIB, but does not cause a GET interrupt.

0101, 1101—Clear/Set rtl: These commands correspond to the local rtl message as defined by the IEEE-488. The 8291A will go into local mode when a Set rtl Auxiliary Command is received if local lockout is not in effect. The 8291A will exit local mode after receiving a Clear rtl Auxiliary Command if the 8291A is addressed to listen.

0110—Send EOI: The EOI line of the 8291A may be asserted with this command. The command causes EOI to go true with the next byte transmitted. The EOI line is then cleared upon completion of the handshake for that byte.

0111, 1111—Non Valid/Valid Secondary Address or Command (VSCMD): This command informs the 8291A that the secondary address received by the microprocessor was valid or invalid (0111 = invalid, 1111 = valid). If Mode 3 addressing is used, the processor must field each extended address and respond to it, or the GPIB will hang up. Note that the COM3 bit is the invalid/valid flag.

The valid (1111) command is also used to tell the 8291A to continue from the command-pass-through-state, or from RFD holdoff on GET, SDC or DCL.

1000—pon: This command puts the 8291A into the pon (power on) state and holds it there. It is similar to a Chip Reset except none of the Auxiliary Mode Registers are cleared. In this state, the 8291A does not participate in any bus activity. An Immediate Execute pon releases the 8291A from the pon state and permits the device to participate in the bus activity again.

0001, 1001—Parallel Poll Flag (local "ist" message): This command sets (1001) or clears (0001) the parallel poll flag. A "1" is sent over the assigned data line (PRR = Parallel Poll Response true) only if the parallel poll flag matches the sense bit from the lpe local message (or indirectly from the PPE message). For a more complete description of the Parallel Poll features and procedures refer to the section on Parallel Poll Protocol.

INTERNAL COUNTER

The internal counter determines the delay time allowed for the setting of data on the DIO lines. This delay time is defined as T_1 in IEEE-488 and appears in the Source Handshake state diagram between the

SDYS and STRS. As such, DAV is asserted T_1 *after* the DIO lines are driven. Consequently, T_1 is a major factor in determining the data transfer rate of the 8291A over the GPIB (T_1 = TWRDV2-TWRD15).

When open-collector transceivers are used for connection to the GPIB, T_1 is defined by IEEE-488 to be 2μsec. By writing 0010DDDD into the Auxiliary Mode Register, the counter is preset to match a f_C MHz clock input, where DDDD is the binary representation of N_F [$1 \leq N_F \leq 8$, $N_F=(DDDD)_2$]. When $N_F = f_C$, a 2μsec T_1 delay will be generated before each DAV asserted.

$$T_{1(\mu sec)} = \frac{2N_F}{f_C} + t_{SYNC}\ ,\ 1 \leq N_F \leq 8$$

t_{SYNC} is a synchronization error, greater than zero and smaller than the larger of T clock high and T clock low. (For a 50% duty cycle clock, t_{SYNC} is less than half the clock cycle).

If it is necessary that T_1 be different from 2μsec, N_F may be set to a value other than f_C. In this manner, data transfer rates may be programmed for a given system. In small systems, for example, where transfer rates exceeding GPIB specifications are required, one may set $N_F < f_C$ and decrease T_1.

When tri-state transceivers are used, IEEE-488 allows a higher transfer rate (lower T_1). Use of the 8291A with such transceivers is enabled by setting B_2 in Auxiliary Register B. In this case, setting $N_F = f_C$ causes a T_1 delay of 2μsec to be generated for the first byte transmitted — all subsequent bytes will have a delay of 500 nsec.

$$T_1(\text{High Speed})\ \mu\text{sec} = \frac{N_F}{2f_C} + t_{SYNC}$$

Thus, the shortest T_1 is achieved by setting $N_F=1$ using an 8 MHz clock with a 50% duty cycle clock (t_{SYNC}<63 nsec):

$$T_{1(HS)} = \frac{1}{2x8} + 0.063 = 125 \text{ nsec max.}$$

AUXILIARY REGISTER A

Auxiliary Register A is a "hidden" 5-bit register which is used to enable some of the 8291A features. Whenever a 100 $A_4A_3A_2A_1A_0$ byte is written into the Auxiliary Register, it is loaded with the data $A_4A_3A_2A_1A_0$. Setting the respective bits to "1" enables the following features.

A_0— RFD Holdoff on all Data: If the 8291A is listening, RFD will not be sent true until the "finish handshake" auxiliary command is issued by the microprocessor. The holdoff will be in effect for each data byte.

A_1—RFD Holdoff on End: This feature enables the holdoff on EOI or EOS (if enabled). However, no holdoff will be in effect on any other data bytes.

A_2—End on EOS Received: Whenever the byte in the Data In Register matches the byte in the EOS Register, the END interrupt bit will be set in the Interrupt Status 1 Register.

A_3—Output EOI on EOS Sent: Any occurrence of data in the Data Out Register matching the EOS Register causes the EOI line to be sent true along with the data.

A_4—EOS Binary Compare: Setting this bit causes the EOS Register to function as a full 8-bit word. When it is not set, the EOS Register is a 7-bit word (for ASCII characters).

If $A_0=A_1=1$, a special "continuous Acceptor Handshake cycling" mode is enabled. This mode should be used only in a controller system configuration, where both the 8291A and the 8292 are used. It provides a continuous cycling through the Acceptor Handshake state diagram, requiring no local messages from the microprocessor; the rdy local message is automatically generated when in ANRS. As such, the 8291A Acceptor Handshake serves as the controller Acceptor Handshake. Thus, the controller cycles through the Acceptor Handshake without delaying the data transfer in progress. When the tcs local message is executed, the 8291A should be taken out of the "continuous AH cycling" mode, the GPIB will hang up in ANRS, and a BI interrupt will be generated to indicate that control may be taken. A simpler procedure may be used when a "tcs on end of block" is executed; the 8291A may stay in "continuous AH cycling". Upon the end of a block (EOI or EOS received), a holdoff is generated, the GPIB hangs up in ANRS, and control may be taken.

AUXILIARY REGISTER B

Auxiliary Register B is a "hidden" 4-bit register which is used to enable some of the features of the 8291A. Whenever a 101 $B_4B_3B_2B_1B_0$ is written into the Auxiliary Mode Register, it is loaded with the data $B_4B_3B_2B_1B_0$. Setting the respective bits to "1" enables the following features:

B_0—Enable Undefined Command Pass Through: This feature allows any commands not recognized by the 8291A to be handled in software. If enabled, this feature will cause the 8291A to holdoff the handshake when an undefined command is received. The microprocessor must then read the command from the Command Pass Through Register and send the VSCMD auxiliary command. Until the VSCMD command is sent, the handshake holdoff will be in effect.

B_1—Send EOI in SPAS: This bit enables EOI to be sent with the status byte; EOI is sent true in Serial Poll Active State. Otherwise, EOI is sent false in SPAS.

B_2—Enable High Speed Data Transfer: This feature may be enabled when tri-state external transceivers are used. The data transfer rate is limited by T_1 delay time generated in the Source Handshake function, which is defined according to the type of transceivers used. When the "High Speed" feature is enabled, T_1 = 2 microseconds is generated for the first byte transmitted after each true to false transition of ATN. For all subsequent bytes, T_1 = 500 nanoseconds. Refer to the Internal Counter section for an explanation of T_1 duration as a function of B_2 and of clock frequency.

B_3—Enable Active Low Interrupt: Setting this bit causes the polarity of the INT pin to be reversed, providing an output signal compatible with Intel's MCS-48® Family. Interrupt registers are not affected by this bit.

B_4—Enable RFD Holdoff on GET or DEC: Setting this bit causes RFD to be held false until the "VSCMD" auxiliary command is written after GET, SDC, and DCL commands. This allows the device to hold off the bus until it has completed a clear or trigger similar to an unrecognized command.

PARALLEL POLL PROTOCOL

Writing a 011U$SP_3P_2P_1$ into the Auxiliary Mode Register will enable (U=0) or disable (U=1) the 8291A for a parallel poll. When U=0, this command is the "lpe" (local poll enable) local message as defined in IEEE-488. The "S" bit is the sense in which the 8291A is enabled; only if the Parallel Poll Flag ("ist" local message) matches this bit will the Parallel Poll Response, PPR_N, be sent true (Response= S + ist). The bits $P_3P_2P_1$ specify which of the eight data lines PPR_N will be sent over. Thus, once the 8291A has been configured for Parallel Poll, whenever it senses both EOI and ATN true, it will automatically compare its PP flag with the sense bit and send PPR_N true or false according to the comparison.

If a PP2* implementation is desired, the "lpe" and "ist" local messages are all that are needed. Typically, the user will configure the 8291A for Parallel Poll immediately after initialization. During normal operation the microprocessor will set or clear the Parallel Poll Flag (ist) according to the device's need for service. Consequently the 8291A will be set up to give the proper response to IDY (EOI · ATN) without directly involving the microprocessor.

If a PP1* implementation is desired, the undefined command features of the 8291A must be used. In PP1, the 8291A is indirectly configured for Parallel Poll by the active controller on the GPIB. The sequence at the 8291A being enabled or disabled remotely is as follows:

1. The PPC message is received and is loaded into the Command Pass Through Register as an undefined command. A CPT Interrupt is sent to the microprocessor; the handshake is automatically held off.

2. The microprocessor reads the CPT Register and sends VSCMD to the 8291A, releasing the handshake.

3. Having received an undefined primary command, the 8291A is set up to receive an undefined secondary command (the PPE or PPD message). This message is also received into the CPT Register, the handshake is held off, and the CPT interrupt is generated.

NOTE: *As defined in IEEE Standard 488.

4. The microprocessor reads the PPE or PPD message and writes the command into the Auxiliary Mode Register (bit 7 should be cleared first). Finally, the microprocessor sends VSCMD and the handshake is released.

End of Sequence (EOS) Register

EC7	EC6	EC5	EC4	EC3	EC2	EC1	EC0

EOS REGISTER

The EOS Register and its features offer an alternative to the "Send EOI" auxiliary command. A seven or eight bit byte (ASCII or binary) may be placed in the register to flag the end of a block or read. The type of EOS byte to be used is selected in Auxiliary Register bit A_4.

If the 8291A is a listener, and the "End on EOS Received" is enabled with bit A_2, then an END interrupt is generated in the Interrupt Status 1 Register whenever the byte in the Data-In Register matches the byte in the EOS Register.

If the 8291A is a talker, and the "Output EOI on EOS Sent" is enabled with bit A_3, then the EOI line is sent true with the next byte whenever the contents of the Data Out Register match the EOS register.

Reset Procedure

The 8291A is reset to an initialization state either by a pulse applied to its Reset pin, or by a reset auxiliary command (02H written into the Auxiliary Command Register). The following conditions are caused by a reset pulse (or local reset command):

1. A "pon" local message as defined by IEEE-488 is held true until the initialization state is released.
2. The Interrupt Status Registers are cleared (not Interrupt Enable Registers).
3. Auxiliary Registers A and B are cleared.
4. The Serial Poll Mode Register is cleared.
5. The Parallel Poll Flag is cleared.
6. The EOI bit in the Address Status Register is cleared.
7. N_F in the Internal Counter is set to 8 MHz. This setting causes the longest possible T_1 delay to be generated in the Source Handshake (16 μsec for 1 MHz clock).
8. The rdy local message is sent.

The initialization state is released by an "immediate execute pon" command (00H written into the Auxiliary Command Register).

The suggested initialization sequence is:

1. Apply a reset pulse or send the reset auxiliary command.
2. Set the desired intial conditions by writing into the Interrupt Enable, Serial Poll Mode, Address Mode, Address 0/1, and EOS Registers. Auxiliary Registers A and B, and the internal counter should also be initialized.
3. Send the "immediate execute pon" auxiliary command to release the initialization state.
4. If a PP2 Parallel Poll implementation is to be used the "lpe" local message may be sent, enabling the 8291A for a Parallel Poll Response on an assigned line. (Refer to the section on Parallel Poll Protocol.)

Using DMA

The 8291A may be connected to the Intel® 8237 or 8257 DMA Controllers or the 8089 I/O Processor for DMA operation. The 8237 will be used to refer to any DMA controller. The DREQ pin of the 8291A requests a DMA byte transfer from the 8237. It is set by BO or BI flip flops, enabled by the DMAO and DMAI bits in the Interrupt Enable 2 Register. (After reading, the INT1 register BO and BI interrupts will be cleared but not BO and BI in DREQ equation.)

The $\overline{DACK}$ pin is driven by the 8237 in response to the DMA request. When $\overline{DACK}$ is true (active low) it sets $\overline{CS}$= RS0= RS1= RS2=0 such that the $\overline{RD}$ and $\overline{WR}$ signals sent by the 8237 refer to the Data In and Data Out Registers. Also, the DMA request line is reset by $\overline{DACK}$ ($\overline{RD}$ + $\overline{WR}$).

DMA input sequence:

1. A data byte is accepted from the GPIB by the 8291A.
2. A BI interrupt is generated and DREQ is set.
3. $\overline{DACK}$ and $\overline{RD}$ are driven by the 8237, the contents of the Data In Register are transferred to the system bus, and DREQ is reset.
4. The 8291A sends RFD true on the GPIB and proceeds with the Acceptor Handshake protocol.

DMA output sequence:

1. A BO interrupt is generated (indicating that a byte should be output) and DREQ is asserted.

2. $\overline{DACK}$ and $\overline{WR}$ are driven by the 8237, a byte is transferred from the MCS bus into the Data Out Register, and DREQ is reset.
3. The 8291A sends DAV true on the GPIB and proceeds with the Source Handshake protocol.

It should be noted that each time the device is addressed (MTA + MLA + ton + lon), the Address Status Register should be read, and the 8237 should be initialized accordingly. (Refer to the 8237 or 8257 Data Sheets.)

APPLICATION BRIEF

System Configuration

MICROPROCESSOR BUS CONNECTION

The 8291A is 8048/49, 8051, 8080/85, and 8086/88 compatible. The three address pins (RS_0, RS_1, RS_2) should be connected to the non-multiplexed address bus (for example: A_8, A_9, A_{10}). In case of 8080, any address lines may be used. If the three lowest address bits are used (A_0, A_1, A_2), then they must be demultiplexed first.

EXTERNAL TRANSCEIVERS CONNECTION

The 8293 GPIB Transceiver interfaces the 8291A directly to the IEEE-488 bus. The 8291A and two 8293's can be configured as a talker/listener (see Figure 6) or with the 8292 as a talker/listener/controller (see Figure 7). Absolutely no active or passive external components are required to comply with the complete IEEE-488 electrical specification.

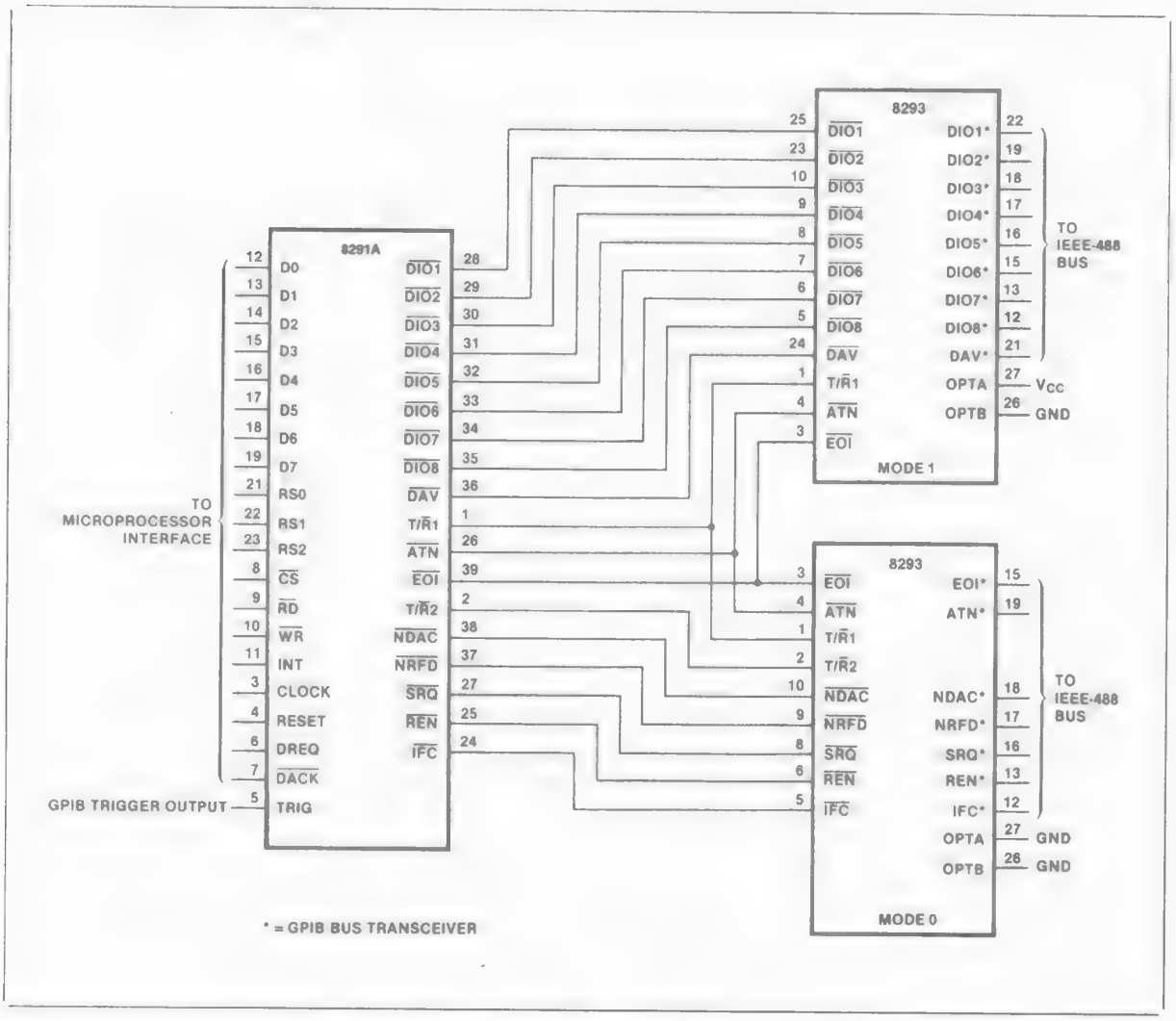


Figure 6. 8291A and 8293 System Configuration

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Start-Up Procedures

The following section describes the steps needed to initialize a typical 8291A system implementing a talker/listener interface and an 8291A/8292 system implementing a talker/listener/controller interface.

TALKER/LISTENER SYSTEM

Assume a general system configuration with the following features: (i) Polled system interface; (ii) Mode 1 addressing; (iii) same address for talker and listener; (iv) ASCII carriage return as the end-of-sequence (EOS) character; (v) EOI sent true with the last byte; and, (vi) 8 MHz clock.

Initialization. Initialization is accomplished with the following steps:

1. Pulse the RESET input or write 02H to the Auxiliary Mode Register.
2. Write 00H to the Interrupt Enable Registers 1 and 2. This disables interrupt and DMA.
3. Write 01H to the Address Mode Register to select Mode 1 addressing.
4. Write 28H to the Auxiliary Mode Register. This loads 8H to the Auxiliary Register A matching the 8 MHz clock input to the internal T1 delay counter to generate the delay meeting the IEEE spec.
5. Write the talker/listener address to the Address 0/1 register. The three most significant bits are zero.
6. Write an ASCII carriage return (0DH) to the EOS register.
7. Write 88H to the Auxiliary Mode Register to allow $\overline{EOI}$ to be sent true when the EOS character is sent.
8. Write 00H to the Auxiliary Mode Register. This writes the "Immediate Execute pon" message and takes the 8291A from the initialization state into the idle state. The 8291A will remain idle until the controller initiates some activity by driving $\overline{ATN}$ true.

Communication. The local CPU now polls the 8291A to determine which controller command has been received.

The controller addresses the 8291A by driving $\overline{ATN}$, placing MLA (My Listen Address) on the bus and driving $\overline{DAV}$. If the lower five bits of the MLA message match the address programmed into the Address 0/1 register, the 8291A is addressed to listen. It would be addressed to talk if the controller sent the MTA message instead of MLA.

The ADSC bit in the Interrupt Status 2 Register indicates that the 8291A has been addressed or unaddressed. The TA and LA bits in the Address Status Register indicate whether the 8291A is talker (TA=1), listener (LA=1), both (TA=LA=1) or unaddressed (TA=LA=0).

If the 8291A is addressed to listen, the local CPU can read the Data-In Register whenever the BI (Byte In) interrupt occurs in the Interrupt Status 1 Register. If the END bit in the same register is also set, either EOI or a data byte matching the pattern in the EOS register has been received.

In the talker mode, the CPU writes data into the Byte-Out Register on BO (Byte Out) true.

TALKER/LISTENER/CONTROLLER SYSTEM

Combined with the Intel 8292, the 8291A executes a complete IEEE-488-1978 controller function, The 8291A talks and listens via the data and handshake lines ($\overline{NRFD}$, $\overline{NDAC}$ and $\overline{DAV}$). The 8292 controls four of the five bus management lines ($\overline{IFC}$, $\overline{SRQ}$, $\overline{ATN}$ and $\overline{REN}$). $\overline{EOI}$, the fifth line, is shared. The 8291A drives and receives $\overline{EOI}$ when $\overline{EOI}$ is used as an end-of-block indicator. The 8292 drives $\overline{EOI}$ along with $\overline{ATN}$ during a parallel poll command.

Once again, assume a general system configuration with the following features: (i) Polled system interface; (ii) 8292 as the system controller and controller-in-charge; (iii) ASCII carriage return (0DH) as the EOS identifier; (iv) $\overline{EOI}$ sent with the last character; and, (v) an external buffer (8282) used to monitor the TCI line.

Initialization. In order to send a command across the GPIB, the 8292 has to drive $\overline{ATN}$, and the 8291A has to drive the data lines. Both devices therefore need initialization.

To initialize the 8292:

1. Pulse the RESET input. The 8292 will initially drive all outputs high. TCI, SPI, OBFI, IBFI and CLTH will then go low. The Interrupt Status, Interrupt Mask, Error Flag, Error Mask and Timeout registers will be cleared. The interrupt counter will be disabled and loaded with 255. The 8292 will then monitor the status of the SYC pin. If high, the 8292 will pulse IFC true for at least 100μs in compliance with the IEEE-488-1978 standard. It will then take control by asserting $\overline{ATN}$.

To initialize the 8291A, the following is necessary:

1. Write 00H to Interrupt Enable registers 1 and 2. This disables interrupt and DMA.

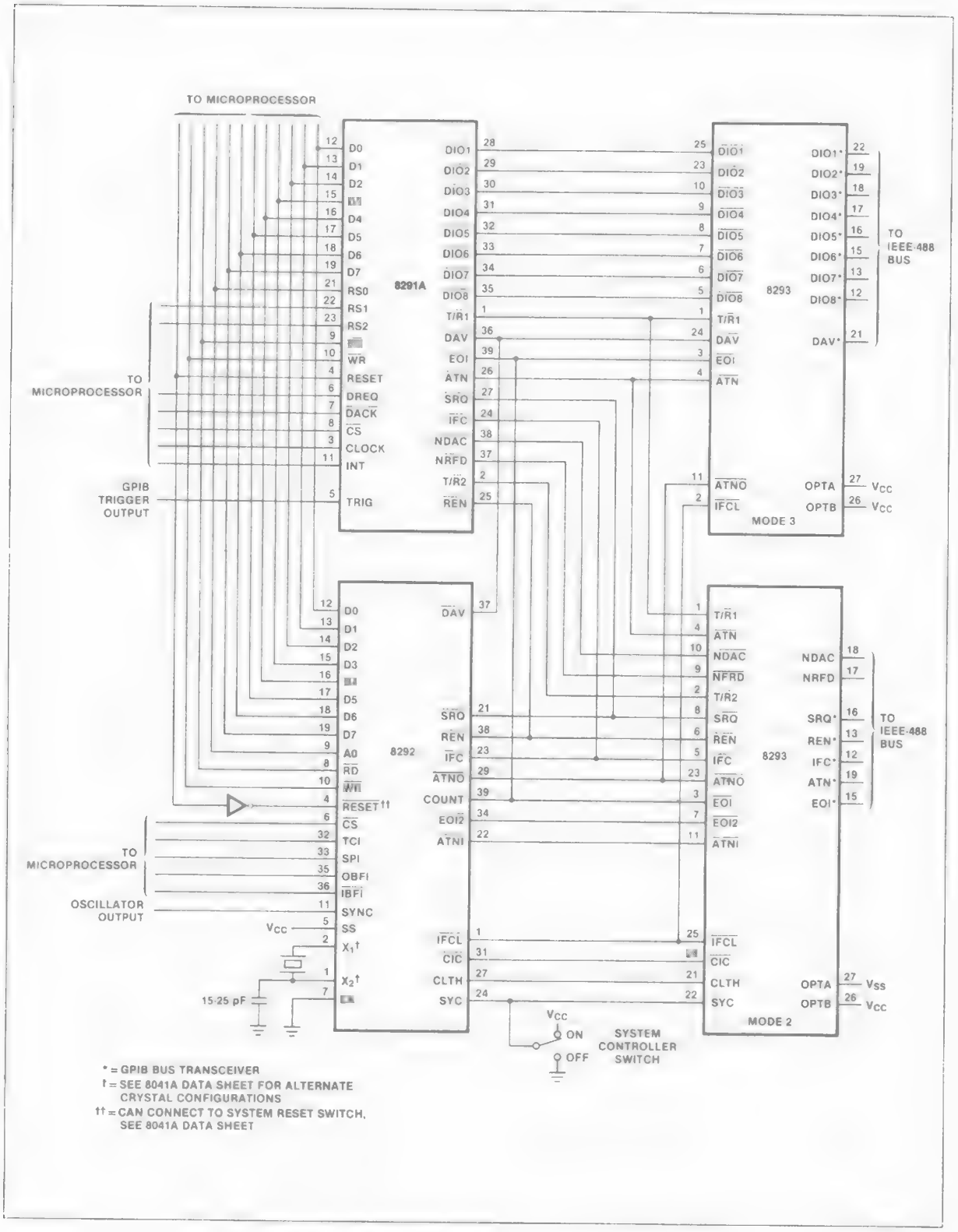

Figure 7. 8291A, 8292, and 8293 System Configuration

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2. With the 8292 as the controller-in-charge, it is impossible to address the 8292 via the GPIB. Therefore, the ton or lon modes of the 8291A must be used. To send comands, set the 8291A in the ton mode by writing 80H to the Address Mode Register.
3. Write 26H to the Auxiliary Mode Register to match the T1 data settling time to the 6 MHz clock input.
4. Write an ASCII carriage return (0DH) to the EOS Register.
5. Write 84H to the Auxiliary Mode Register in order to enable "Output EOI on EOS sent" and thus send EOI with the last character.
6. Write 00H—Immediate Execute pon—to the Auxiliary Mode Register to put the 8291A in the idle state.

Communication. Since the 8291A is in the ton mode, a BO interrupt is generated as soon as the immediate Execute pon command is written. The CPU writes the command into the Data Out Register, and repeats it on BO becoming true for as many commands as necessary. $\overline{ATN}$ remains continuously true unless the GTSB (Go To Standby) command is sent to the 8292.

$\overline{ATN}$ has to be false in order to send data rather than commands from the controller. To do this, the following steps are needed:

1. Enable the TCI interrupt if not already enabled.
2. Wait for IBF (Input Buffer Full) in the 8292 Interrupt Status Register to be reset.
3. Write the GTSB (F6H) command to the 8292 Command Field Register.
4. Read the 8282 and wait for TCI to be true.
5. Write the ton (80H) and pon (00H) command to the 8291A Address Mode Register and Auxiliary Mode Registers respectively.
6. Wait for the BO interrupt to be set in the 8291A.
7. Write the data to the 8291A Data-Out Register.

Identically, the user could command the controller to listen rather than talk. To do that, write lon (40H) instead of ton into the Address Mode Register. Then wait for BI rather than BO to go true. Read the data Register.

ABSOLUTE MAXIMUM RATINGS

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage on Any Pin
With Respect to Ground ..... −0.5V to +7V
Power Dissipation ..... 0.65 Watts

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS [V_{CC} = 5V ±10%, T_A = 0°C to 70°C (Commercial)]

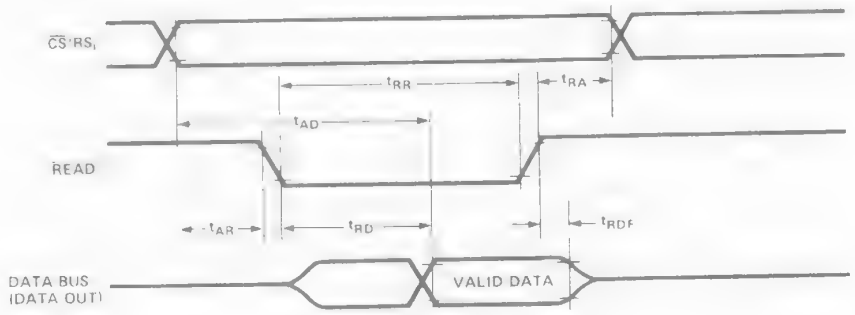
Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_{IL}	Input Low Voltage	-0.5	0.8	V	
V_{IH}	Input High Voltage	2	V_{CC}+0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL}=2mA (4mA for TR1 pin)
V_{OH}	Output High Voltage	2.4		V	I_{OH} = -400μA (-150μA for SRQ pin)
$V_{OH\ INT}$	Interrupt Output High Voltage	2.4 3.5		V V	I_{OH}=-400μA I_{OH}=-50μA
I_{IL}	Input Leakage		10	μA	V_{IN}=0V to V_{CC}
I_{IOFL}	Output Leakage Current		±10	μA	V_{OUT}=0.45V, V_{CC}
I_{CC}	V_{CC} Supply Current		120	mA	T_A=0°C

A.C. CHARACTERISTICS [V_{CC} = 5V ±10%, T_A = 0°C to 70°C (Commercial)]

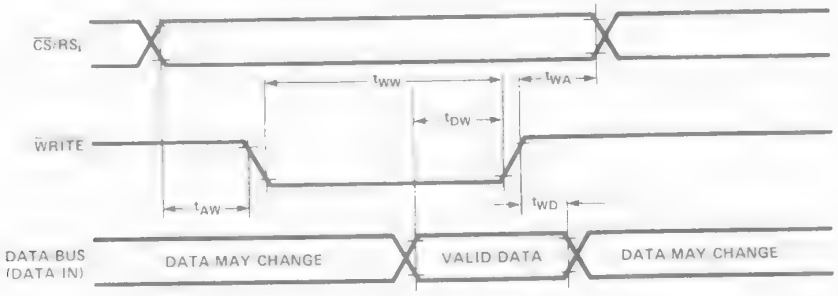
Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AR}	Address Stable Before $\overline{READ}$	0		nsec	
t_{RA}	Address Hold After $\overline{READ}$	0		nsec	
t_{RR}	$\overline{READ}$ width	140		nsec	
t_{AD}	Address Stable to Data Valid		250	nsec	
t_{RD}	$\overline{READ}$ to Data Valid		100	nsec	
t_{RDF}	Data Float After $\overline{READ}$	0	60	nsec	
t_{AW}	Address Stable Before $\overline{WRITE}$	0		nsec	
t_{WA}	Address Hold After $\overline{WRITE}$	0			
t_{WW}	$\overline{WRITE}$ Width	170		nsec	
t_{DW}	Data Set Up Time to the Trailing Edge of $\overline{WRITE}$	130		nsec	
t_{WD}	Data Hold Time After $\overline{WRITE}$	0		nsec	
t_{DKDR4}	$\overline{RD}$↓ or $\overline{WR}$↓ to DREQ↓		130	nsec	
t_{DKDA6}	$\overline{RD}$↓ to Valid Data (D_0–D_7)		200	nsec	$\overline{DACK}$↓ to $\overline{RD}$↓ 0 ≤t ≤50nsec

WAVEFORMS

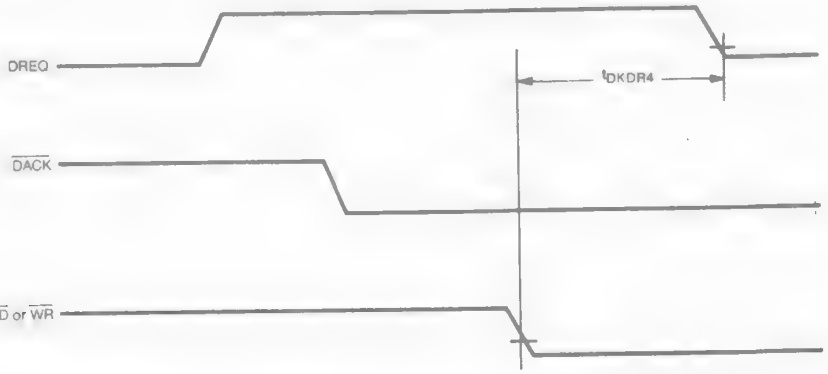
READ



WRITE



DMA



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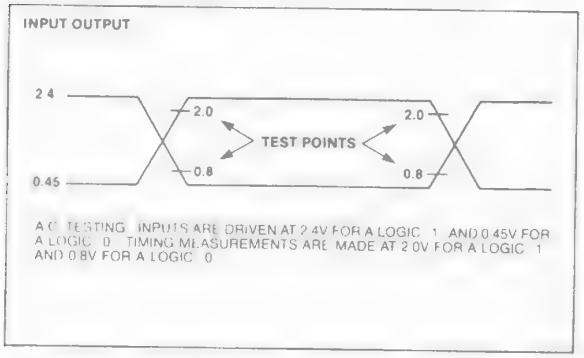
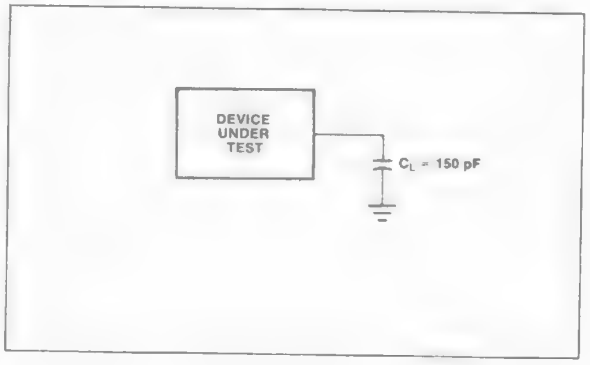
A.C. TIMING MEASUREMENT POINTS AND LOAD CONDITIONS





GPIB TIMINGS[1]

Symbol	Parameter	Max.	Units	Test Conditions
TEOT13[2]	$\overline{EOI}$↓ to TR1↑	135	nsec	PPSS, ATN=0.45V
TEOD16	$\overline{EOI}$↓ to $\overline{DIO}$ Valid	155	nsec	PPSS, ATN=0.45V
TEOT12	$\overline{EOI}$↑ to TR1↓	155	nsec	PPSS, ATN=0.45V
TATND4	$\overline{ATN}$↓ to $\overline{NDAC}$↓	155	nsec	TACS, AIDS
TATT14	$\overline{ATN}$↓ to TR1↓	155	nsec	TACS, AIDS
TATT24	$\overline{ATN}$↓ to TR2↓	155	nsec	TACS, AIDS
TDVND3-C	$\overline{DAV}$↓ to $\overline{NDAC}$↑	650	nsec	AH, CACS
TNDDV1	$\overline{NDAC}$↑ to $\overline{DAV}$↑	350	nsec	SH, STRS
TNRDR1	$\overline{NRFD}$↑ to DREQ↑	400	nsec	SH
TDVDR3	$\overline{DAV}$↓ to DREQ↑	600	nsec	AH, LACS, ATN=2.4V
TDVND2-C	$\overline{DAV}$↑ to $\overline{NDAC}$↓	350	nsec	AH, LACS
TDVNR1-C	$\overline{DAV}$↑ to $\overline{NRFD}$↑	350	nsec	AH, LACS, rdy=True
TRDNR3	$\overline{RD}$↓ to $\overline{NRFD}$↑	500	nsec	AH, LACS
TWRD15	$\overline{WR}$↑ to $\overline{DIO}$ Valid	280	nsec	SH, TACS, RS=0.4V
TWREO5	$\overline{WR}$↑ to $\overline{EOI}$ Valid	350	nsec	SH, TACS
TWRDV2	$\overline{WR}$↑ to $\overline{DAV}$↓	$830 + t_{SYNC}$	nsec	High Speed Transfers Enabled, $N_F = f_C$, $t_{SYNC} = 1/2 \cdot f_C$

NOTES:

1. All GPIB timings are at the pins of the 8291A.
2. The last number in the symbol for any GPIB timing parameter is chosen according to the transition directions of the reference signals. The following table describes the numbering scheme.

↑ to ↑	1
↑ to ↓	2
↓ to ↑	3
↓ to ↓	4
↑ to VALID	5
↓ to VALID	6

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APPENDIX A

MODIFIED STATE DIAGRAMS

Figure A-1 presents the interface function state diagrams. It is derived from IEEE Std. state diagrams, with the following changes:

A. The 8291A supports the complete set of IEEE-488 interface functions except for the controller. These include: SH1, AH1, T5, TE5, L3, LE3, SR1, RL1, PP1, DC1, DT1, and C0.

B. Addressing modes included in T,L state diagrams.

Note that in Mode 3, MSA, OSA are generated only after secondary address validity check by the microprocessor (APT interrupt).

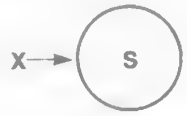
C. In these modified state diagrams, the IEEE-488-1978 convention of negative (low true) logic is followed. This should not be confused with the Intel pin- and signal-naming convention based on positive logic. Thus, while the state diagrams below carry low true logic, the signals described elsewhere in this data sheet are consistent with Intel notation and are based on positive logic.

Level	Logic	Convention IEEE-488	Convention Intel
0	T	DAV	$\overline{DAV}$
1	F	$\overline{DAV}$	DAV
0	T	NDAC	$\overline{NDAC}$
1	F	$\overline{NDAC}$	NDAC
0	T	NRFD	$\overline{NRFD}$
1	F	$\overline{NRFD}$	NRFD

Consider the condition when the Not-Ready-For-Data signal (pin 37) is active. Intel indicates this active low signal with the symbol $\overline{NRFD}$ ($V_{OUT} \leq V_{OL}$ for AH; $V_{IN} \leq V_{IL}$ for SH). The IEEE-488-1978 Standard, in its state diagrams, indicates the active state of this signal (True condition) with NRFD.

D. All remote multiline messages decoded are conditioned by ACDS. The multiplication by ACDS is not drawn to simplify the diagrams.

E. The symbol



indicates:

1. When event X occurs, the function returns to state S.
2. X overrides any other transition condition in the function.

Statement 2 simplifies the diagram, avoiding the explicit use of X to condition all transitions from S to other states.

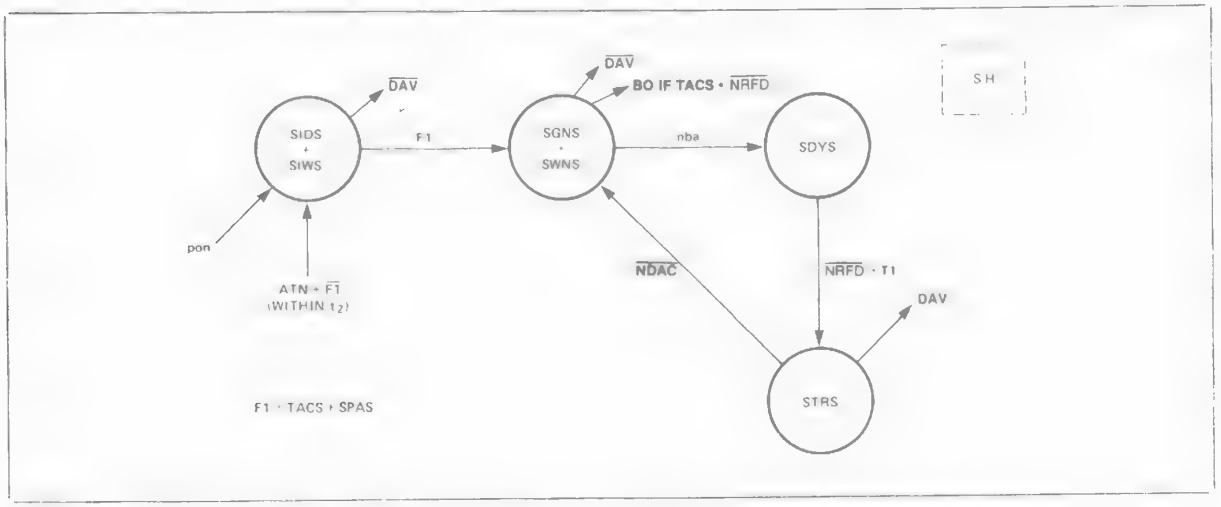


Figure A-1. 8291A State Diagrams (Continued next page)

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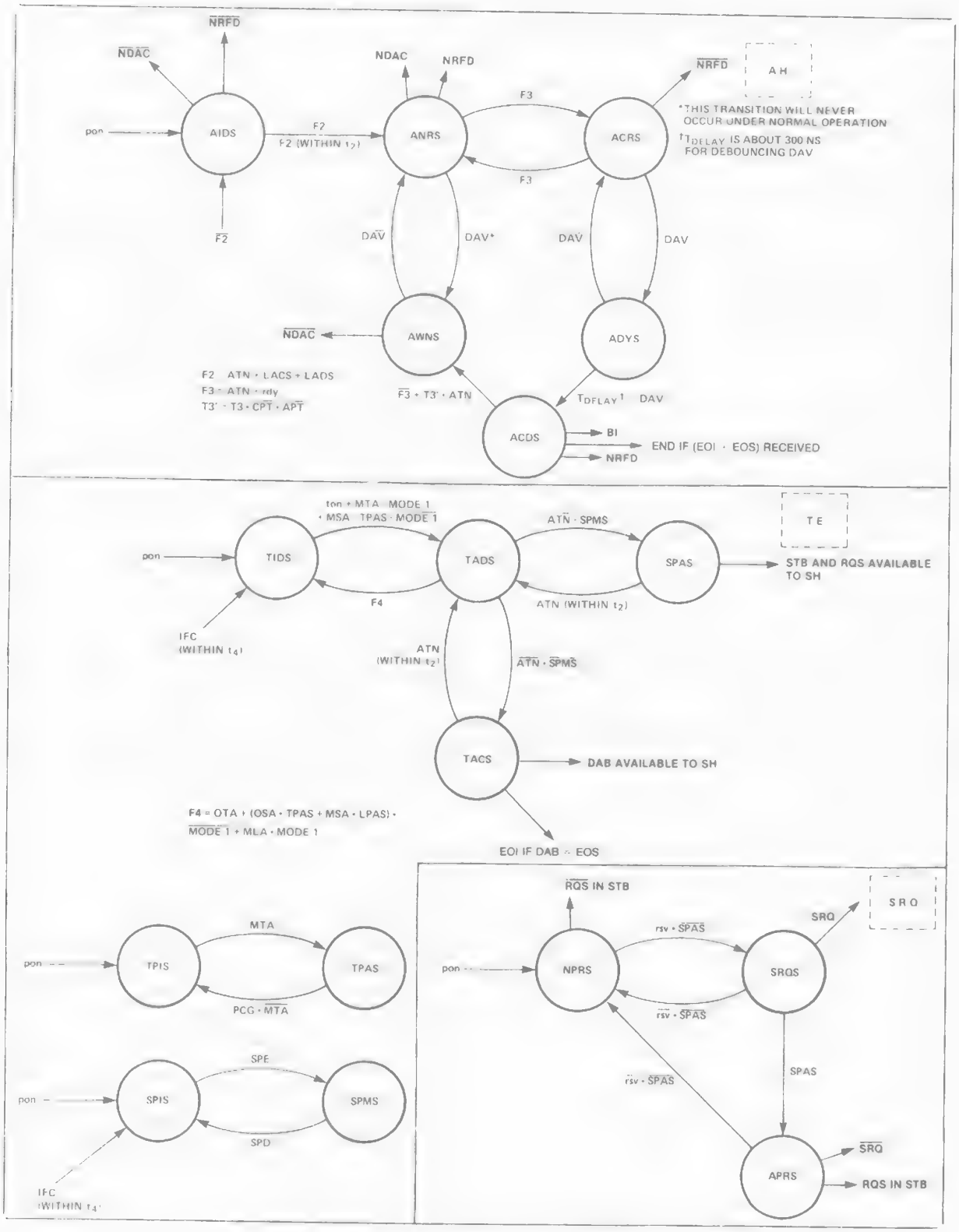

Figure A-1. 8291A State Diagrams (Continued next page)

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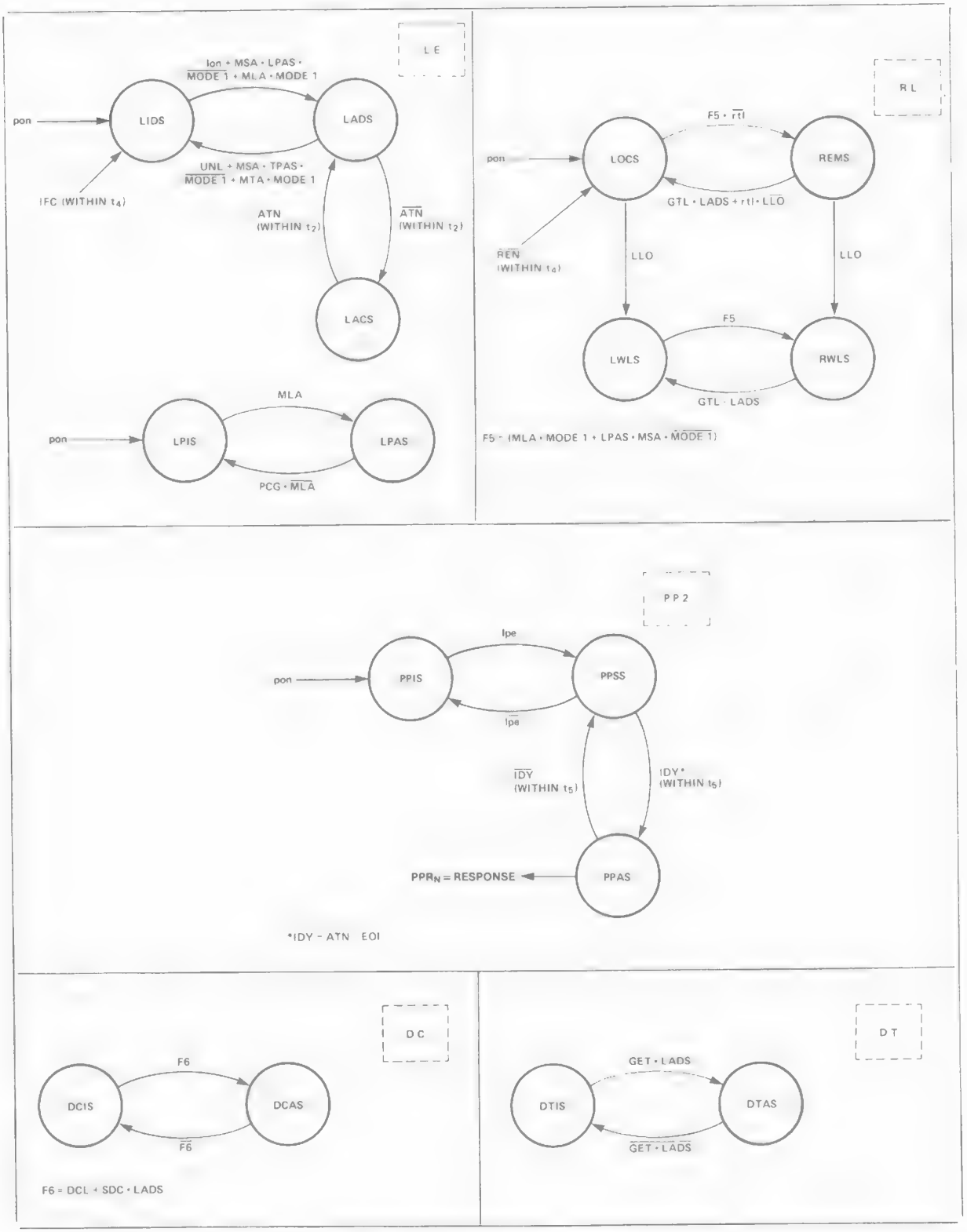

Figure A-1. 8291A State Diagrams

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APPENDIX B

Table B-1. IEEE 488 Time Values

Time Value Identifier[1]	Function (Applies to)	Description	Value
T_1	SH	Settling Time for Multiline Messages	≥ 2μs[2]
t_2	LC,$\overline{IC}$,SH,AH,T,L	Response to ATN	≤ 200ns
T_3	AH	Interface Message Accept Time[3]	> 0[4]
t_4	T,TE,L,LE,C,CE	Response to IFC or REN False	< 100μs
t_5	PP	Response to ATN+EOI	≤ 200ns
T_6	C	Parallel Poll Execution Time	≥ 2μs
T_7	C	Controller Delay to Allow Current Talker to see ATN Message	≥ 500 ns
T_8	C	Length of IFC or REN False	· 100μs
T_9	C	Delay for EOI[5]	≥ 1.5μs[6]

NOTES:

[1]Time values specified by a lower case t indicate the maximum time allowed to make a state transition. Time values specified by an upper case T indicate the minimum time that a function must remain in a state before exiting.

[2]If three-state drivers are used on the $\overline{DIO}$, $\overline{DAV}$, and $\overline{EOI}$ lines, T_1 may be:

1. ≥ 1100 ns.
2. Or ≥ 700 ns if it is known that within the controller ATN is driven by a three-state driver.
3. Or · · 500ns for all subsequent bytes following the first sent after each false transition of ATN (the first byte must be sent in accordance with (1) or (2).
4. Or · · 350ns for all subsequent bytes following the first sent after each false transition of ATN under conditions specified in Section 5.2.3 and warning note. See IEEE Standard 488.

[3]Time required for interface functions to accept, not necessarily respond to interface messages.

[4]Implementation dependent.

[5]Delay required for $\overline{EOI}$, $\overline{NDAC}$, and $\overline{NRFD}$ signal lines to indicate valid states.

[6] · 600 ns for three-state drivers.

APPENDIX C
THE THREE-WIRE HANDSHAKE

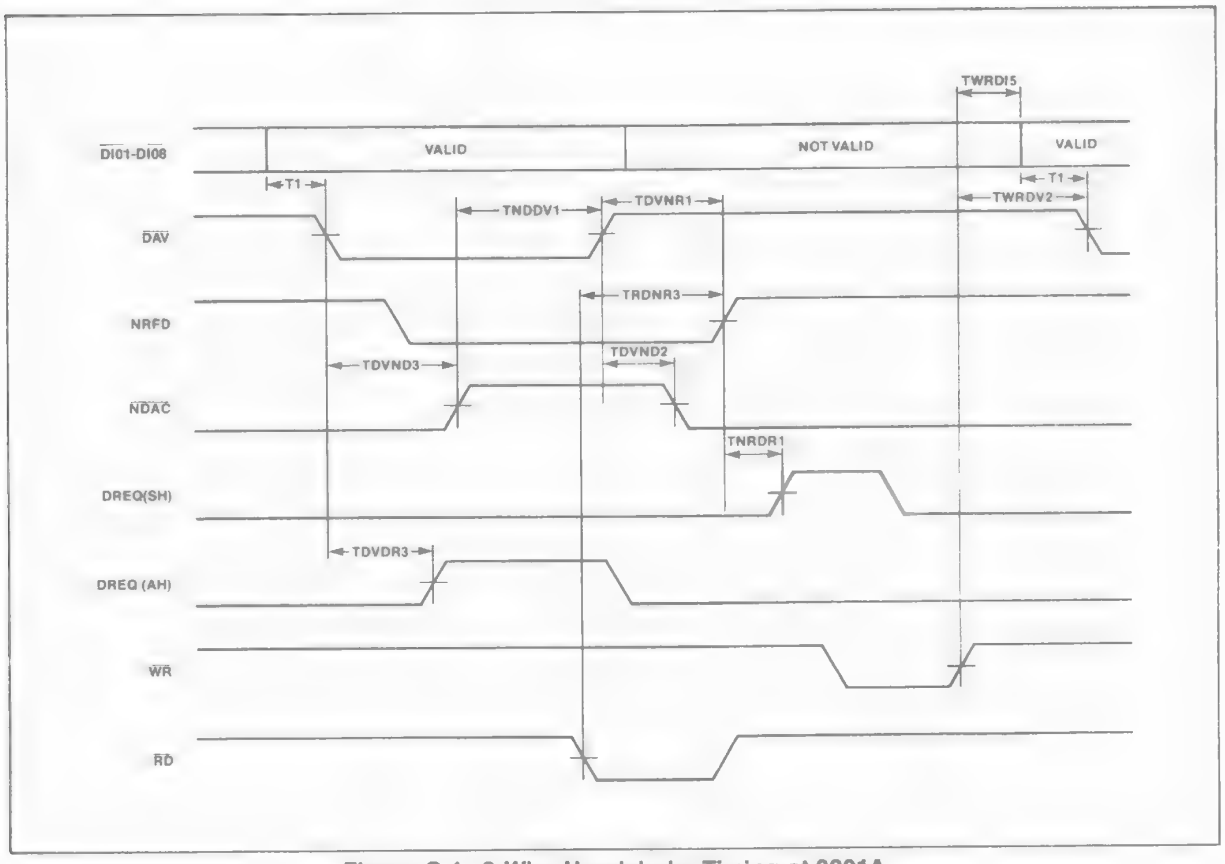

Figure C-1. 3-Wire Handshake Timing at 8291A

AFN-00229B

8292
GPIB CONTROLLER

- Complete IEEE Standard 488 Controller Function
- Interface Clear (IFC) Sending Capability Allows Seizure of Bus Control and/or Initialization of the Bus
- Responds to Service Requests (SRQ)
- Sends Remote Enable (REN), Allowing Instruments to Switch to Remote Control
- Complete Implementation of Transfer Control Protocol
- Synchronous Control Seizure Prevents the Destruction of Any Data Transmission in Progress
- Connects with the 8291 to Form a Complete IEEE Standard 488 Interface Talker/Listener/Controller

The 8292 GPIB Controller is a microprocessor-controlled chip designed to function with the 8291 GPIB Talker/Listener to implement the full IEEE Standard 488 controller function, including transfer control protocol. The 8292 is a pre-programmed Intel® 8041A.

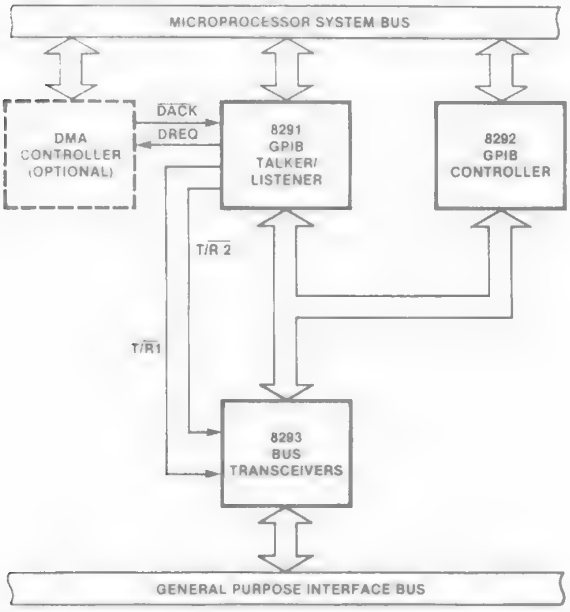

Figure 1. 8291, 8292 Block Diagram

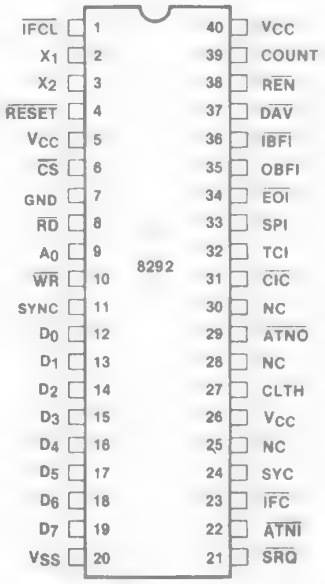

Figure 2. Pin Configuration

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
$\overline{IFCL}$	1	I	**IFC Received (Latched):** The 8292 monitors the IFC Line (when not system controller) through this pin.
X_1, X_2	2, 3	I	**Crystal Inputs:** Inputs for a crystal, LC or an external timing signal to determine the internal oscillator frequency.
$\overline{RESET}$	4	I	**Reset:** Used to initialize the chip to a known state during power on.
$\overline{CS}$	6	I	**Chip Select Input:** Used to select the 8292 from other devices on the common data bus.
$\overline{RD}$	[illegible]	I	**Read Enable:** Allows the master CPU to read from the 8292.
A_0	9	I	**Address Line:** Used to select between the data bus and the status register during read operations and to distinguish between data and commands written into the 8292 during write operations.
$\overline{WR}$	10	I	**Write Enable:** Allows the master CPU to write to the 8292.
SYNC	11	O	**Sync:** 8041A instruction cycle synchronization signal; it is an output clock with a frequency of XTAL ÷ 15.
D_0–D_7	12-19	I/O	**Data:** 8 bidirectional lines used for communication between the central processor and the 8292's data bus buffers and status register.
V_{SS}	7, 20	P.S.	**Ground:** Circuit ground potential.
$\overline{SRQ}$	21	I	**Service Request:** One of the IEEE control lines. Sampled by the 8292 when it is controller in charge. If true, SPI interrupt to the master will be generated.
$\overline{ATNI}$	22	I	**Attention In:** Used by the 8292 to monitor the GPIB ATN control line. It is used during the transfer control procedure.
$\overline{IFC}$	23	I/O	**Interface Clear:** One of the GPIB management lines, as defined by IEEE Std. 488-1978, places all devices in a known quiescent state.
SYC	24	I	**System Controller:** Monitors the system controller switch.
CLTH	27	O	**Clear Latch:** Used to clear the $\overline{IFCR}$ latch after being recognized by the 8292. Usually low (except after hardware Reset), it will be pulsed high when $\overline{IFCR}$ is recognized by the 8292.
$\overline{ATNO}$	[illegible]	O	**Attention Out:** Controls the ATN control line of the bus through external logic for tcs and tca procedures. (ATN is a GPIB control line, as defined by IEEE Std. 488-1978.)
V_{CC}	5, 26, 40	P.S.	**Voltage:** +5V supply input ±10%.
COUNT	39	I	**Event Count:** When enabled by the proper command the internal counter will count external events through this pin. High to low transition will increment the internal counter by one. The pin is sampled once per three internal instruction cycles (7.5μsec sample period when using 5 MHz XTAL). It can be used for byte counting when connected to NDAC, or for block counting when connected to the EOI.
$\overline{REN}$	[illegible]	O	**Remote Enable:** The Remote Enable bus signal selects remote or local control of the device on the bus. A GPIB bus management line, as defined by IEEE Std. 488-1978.
$\overline{DAV}$	37	I/O	**Data Valid:** Used during parallel poll to force the 8291 to accept the parallel poll status bits. It is also used during the tcs procedure.
$\overline{IBFI}$	36	O	**Input Buffer Not Full:** Used to interrupt the central processor while the input buffer of the 8292 is empty. This feature is enabled and disabled by the interrupt mask register.
OBFI	35	O	**Output Buffer Full:** Used as an interrupt to the central processor while the output buffer of the 8292 is full. The feature can be enabled and disabled by the interrupt mask register.
$\overline{EOI2}$	34	I/O	**End Or Identify:** One of the GPIB management lines, as defined by IEEE Std. 488-1978. Used with ATN as Identify Message during parallel poll.
SPI	33	O	**Special Interrupt:** Used as an interrupt on events not initiated by the central processor.
TCI	32	O	**Task Complete Interrupt:** Interrupt to the control processor used to indicate that the task requested was completed by the 8292 and the information requested is ready in the data bus buffer.
CIC	31	O	**Controller In Charge:** Controls the S/R input of the SRQ bus transceiver. It can also be used to indicate that the 8292 is in charge of the GPIB bus.

FUNCTIONAL DESCRIPTION

The 8292 is an Intel 8041A which has been programmed as a GPIB Controller interface element. It is used with the 8291 GPIB Talker/Listener and two 8293 GPIB Transceivers to form a complete IEEE-488 Bus Interface for a microprocessor. The electrical interface is performed by the transceivers, data transfer is done by the talker/listener, and control of the bus is done by the 8292. Figure 3 is a typical controller interface using Intel's GPIB peripherals.

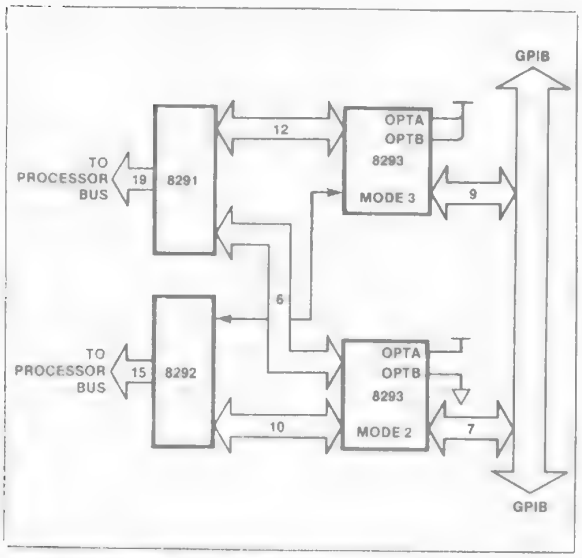

Figure 3. Talker/Listener/Controller Configuration

The internal RAM in the 8041A is used as a special purpose register bank for the 8292. Most of these registers (except for the interrupt flag) can be accessed through commands to the 8292. Table 2 identifies the registers used by the 8292 and how they are accessed.

Interrupt Status Register

SYC	ERR	SRQ	EV	X	IFCR	IBF	OBF
D_7							D_0

The 8292 can be configured to interrupt the microprocessor on one of several conditions. Upon receipt of the interrupt the microprocessor must read the 8292 interrupt status register to determine which event caused the interrupt, and then the appropriate subroutine can be performed. The interrupt status register is read with A_0 high. With the exception of OBF and IBF, these interrupts are enabled or disabled by the SPI interrupt mask. OBF and IBF have their own bits in the interrupt mask (OBFI and $\overline{\text{IBFI}}$).

OBF Output Buffer Full. A byte is waiting to be read by the microprocessor. This flag is cleared when the output data bus buffer is read.

IBF Input Buffer Full. The byte previously written by the microprocessor has not been read yet by the 8292. If another byte is written to the 8292 before this flag clears, data will be lost. IBF is cleared when the 8292 reads the data byte.

IFCR Interface Clear Received. The GPIB system controller has set IFC. The 8292 has become idle and is no longer in charge of the bus. The flag is cleared when the IACK command is issued.

EV Event Counter Interrupt. The requested number of blocks or data bytes has been transferred. The EV interrupt flag is cleared by the IACK command.

SRQ Service Request. Notifies the 8292 that a service request (SRQ) message has been received. It is cleared by the IACK command.

ERR Error occurred. The type of error can be determined by reading the error status register. This interrupt flag is cleared by the IACK command.

SYC System Controller Switch Change. Notifies the processor that the state of the system controller switch has changed. The actual state is contained in the GPIB Status Register. This flag is cleared by the IACK command.

Table 2. 8292 Registers

READ FROM 8292

									A_0
INTERRUPT STATUS									
SYC	ERR	SRQ	EV	X	IFCR	IBF	OBF		1
D_7							D_0		
ERROR FLAG									
X	X	USER	X	X	$TOUT_3$	$TOUT_2$	$TOUT_1$		0*
CONTROLLER STATUS									
CSBS	CA	X	X	SYCS	IFC	REN	SRQ		0*
GPIB (BUS) STATUS									
REN	DAV	EOI	X	SYC	IFC	ANTI	SRQ		0*
EVENT COUNTER STATUS									
D	D	D	D	D	D	D	D		0*
TIME OUT STATUS									
D	D	D	D	D	D	D	D		0*

WRITE TO 8292

									A_0
INTERRUPT MASK									
1	SPI	TCI	SYC	OBFI	$\overline{\text{IBFI}}$	0	SRQ		0
D_7							D_0		
ERROR MASK									
0	0	USER	0	0	$TOUT_3$	$TOUT_2$	$TOUT_1$		0
COMMAND FIELD									
1	1	1	OP	C	C	C	C		1
EVENT COUNTER									
D	D	D	D	D	D	D	D		0*
TIME OUT									
D	D	D	D	D	D	D	D		0*

Note: These registers are accessed by a special utility command, see page 6.

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Interrupt Mask Register

1	SPI	TCI	SYC	OBFI	$\overline{IBFI}$	0	SRQ
D_7							D_0

The Interrupt Mask Register is used to enable features and to mask the SPI and TCI interrupts. The flags in the Interrupt Status Register will be active even when masked out. The Interrupt Mask Register is written when A_0 is low and reset by the RINM command. When the register is read, D_1 and D_7 are undefined. An intertupt is enabled by setting the corresponding register bit.

SRQ Enable interrupts on SRQ received.

$\overline{IBFI}$ Enable interrupts on input buffer empty.

OBFI Enable interrupts on output buffer full.

SYC Enable interrupts on a change in the system controller switch.

TCI Enable interrupts on the task completed.

SPI Enable interrupts on special events.

NOTE: The event counter is enabled by the GSEC command, the error interrupt is enabled by the error mask register, and IFC cannot be masked (it will always cause an interrupt).

Controller Status Register

CSBS	CA	X	X	SYCS	IFC	REN	
D_7							D_0

The Controller Status Register is used to determine the status of the controller function. This register is accessed by the RCST command.

SRQ Service Request line active (CSRS).

REN Sending Remote Enable.

IFC Sending or receiving interface clear.

SYCS System Controller Switch Status (SACS).

CA Controller Active (CACS + CAWS + CSWS).

CSBS Controller Stand-by State (CSBS, CA) = (0,0) — Controller Idle

GPIB Bus Status Register

REN	DAV	EOI	X	SYC	IFC	ATNI	SRQ
D_7							D_0

This register contains GPIB bus status information. It can be used by the microprocessor to monitor and manage the bus. The GPIB Bus Register can be read using the RBST command.

Each of these status bits reflect the current status of the corresponding pin on the 8292.

SRQ Service Request

ATNI Attention In

IFC Interface Clear

SYC System Controller Switch

EOI End or Identify

DAV Data Valid

REN Remote Enable

Event Counter Register

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0

The Event Counter Register contains the initial value for the event counter. The counter can count pulses on pin 39 of the 8292 (COUNT). It can be connected to EOI or NDAC to count blocks or bytes respectively during standby state. A count of zero equals 256. This register cannot be read, and is written using the WEVC command.

Event Counter Status Register

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0

This register contains the current value in the event counter. The event counter counts back from the initial value stored in the Event Counter Register to zero and then generates an Event Counter Interrupt. This register cannot be written and can be read using a REVC command.

Time Out Register

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0

The Time Out Register is used to store the time used for the time out error function. See the individual timeouts (TOUT1, 2, 3) to determine the units of this counter. This Time Out Register cannot be read, and it is written with the WTOUT command.

Time Out Status Register

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0

This register contains the current value in the time out counter. The time out counter decrements from the original value stored in the Time Out Register. When zero is reached, the appropriate error interrupt is generated. If the register is read while none of the time out functions are active, the register will contain the last value reached the last time a function was active. The Time Out Status Register cannot be written, and it is read with the RTOUT command.

Error Flag Register

X	X	USER	X	X	$TOUT_3$	$TOUT_2$	$TOUT_1$
D_7							D_0

Four errors are flagged by the 8292 with a bit in the Error Flag Register. Each of these errors can be masked by the Error Mask Register. The Error Flag Register cannot be written, and it is read by the IACK command when the error flag in the Interrupt Status Register is set.

TOUT1 Time Out Error 1 occurs when the current controller has not stopped sending ATN after receiving the TCT message for the time period specified by the Time Out Register. Each count in the Time Out Register is at least 1800 t_{CY}. After flagging the error, the 8292 will remain in a loop trying to take control until the current controller stops sending ATN or a new command is written by the microprocessor. If a new command is written, the 8292 will return to the loop after executing it.

TOUT2 Time Out Error 2 occurs when the transmission between the addressed talker and listener has not started for the time period specified by the Time Out Register. Each count in the Time Out Register is at least 45 t_{CY}. This feature is only enabled when the controller is in the CSBS state.

TOUT3 Time Out Error 3 occurs when the handshake signals are stuck and the 8292 is not succeeding in taking control synchronously for the time period specified by the Time Out Register. Each count in the Time Out Register is at least 1800 t_{CY}. The 8292 will continue checking $\overline{ATNI}$ until it becomes true or a new command is received. After performing the new command, the 8292 will return to the $\overline{ATNI}$ checking loop.

USER User error occurs when request to assert IFC or REN was received and the 8292 was not the system controller.

Error Mask Register

0	0	USER	0	0	$TOUT_3$	$TOUT_2$	$TOUT_1$
D_7							D_0

The Error Mask Register is used to mask the interrupt from a particular type of error. Each type of error interrupt is enabled by setting the corresponding bit in the Error Mask Register. This register can be read with the RERM command and written with A_0 low.

Command Register

1	1	1	OP	C	C	C	C
D_7							D_0

Commands are performed by the 8292 whenever a byte is written with A_0 high. There are two categories of commands distinguished by the OP bit (bit 4). The first category is the operation command (OP = 1). These commands initiate some action on the interface bus. The second category is the utility commands (OP = 0). These commands are used to aid the communication between the processor and the 8292.

OPERATION COMMANDS

Operation commands initiate some action on the GPIB interface bus. It is using these commands that the control functions such as polling, taking and passing control, and system controller functions are performed.

F0 — SPCNI — Stop Counter Interrupts

This command disables the internal counter interrupt so that the 8292 will stop interrupting the master on event counter underflows. However, the counter will continue counting and its contents can still be used.

F1 — GIDL — Go To Idle

This command is used during the transfer of control procedure while transferring control to another controller. The 8292 will respond to this command only if it is in the active state. $\overline{ATNO}$ will go high, and $\overline{CIC}$ will be high so that this 8292 will no longer be driving the ATN line on the GPIB interface bus. TCI will be set upon completion.

F2 — RST — Reset

This command has the same effect as asserting the external reset on the 8292. For details, refer to the reset procedure described later.

F3 — RSTI — Reset Interrupts

This command resets any pending interrupts and clears the error flags. The 8292 will not return to any loop it was in (such as from the time out interrupts).

F4 — GSEC — Go To Standby, Enable Counting

The function causes $\overline{ATNO}$ to go high and the counter will be enabled. If the 8292 was not the active controller, this command will exit immediately. If the 8292 is the active controller, the counter will be loaded with the value stored in the Event Counter Register, and the internal interrupt will be enabled so that when the counter reaches zero, the SPI interrupt will be generated. SPI will be generated every 256 counts thereafter until the controller exits the standby state or the SPCNI command is written. An initial count of 256 (zero in the Event Counter Register) will be used if the WEVC command is not executed. If the data transmission does not start, a TOUT2 error will be generated.

F5 — EXPP — Execute Parallel Poll

This command initiates a parallel poll by asserting EOI when ATN is already active. TCI will be set at the end of the command. The 8291 should be previously configured as a listener. Upon detection of DAV true, the 8291 enters ACDS and latches the parallel poll response (PPR) byte into its data in register. The master will be interrupted by the 8291 BI interrupt when the PPR byte is available. No interrupts except the $\overline{IBFI}$ will be generated by the 8292. The 8292 will respond to this command only when it is the active controller.

F6 — GTSB — Go To Standby

If the 8292 is the active controller, $\overline{ATNO}$ will go high then TCI will be generated. If the data transmission does not start, a TOUT2 error will be generated.

F7 — SLOC — Set Local Mode

If the 8292 is the system controller, then REN will be asserted false and TCI will be set true. If it is not the system controller, the User Error bit will be set in the Error Flag Register.

F8 — SREM — Set Interface To Remote Control

This command will set REN true and TCI true if this 8292 is the system controller. If not, the User Error bit will be set in the Error Flag Register.

F9 — ABORT — Abort All Operation, Clear Interface

This command will cause IFC to be asserted true for at least 100 μsec if this 8292 is the system controller. If it is in CIDS, it will take control over the bus (see the TCNTR command).

FA — TCNTR — Take Control

The transfer of control procedure is coordinated by the master with the 8291 and 8292. When the master receives a TCT message from the 8291, it should issue the TCNTR command to the 8292. The following events occur to take control:

1. The 8292 checks to see if it is in CIDS, and if not, it exits.
2. Then $\overline{ATNI}$ is checked until it becomes high. If the current controller does not release ATN for the time specified by the Time Out Register, then a TOUT1 error is generated. The 8292 will return to this loop after an error or any command except the RST and RSTI commands.
3. After the current controller releases ATN, the 8292 will assert $\overline{ATNO}$ and $\overline{CIC}$ low.
4. Finally, the TCI interrupt is generated to inform the master that it is in control of the bus.

FC — TCASY — Take Control Asynchronously

TCAS transfers the 8292 from CSBS to CACS independent of the handshake lines. If a bus hangup is detected (by an error flag), this command will force the 8292 to take control (asserting ATN) even if the AH function is not in ANRS (Acceptor Not Ready State). This command should be used very carefully since it may cause the loss of a data byte. Normally, control should be taken synchronously. After checking the controller function for being in the CSBS (else it will exit immediately), $\overline{ATNO}$ will go low, and a TCI interrupt will be generated.

FD — TCSY — Take Control Synchronously

There are two different procedures used to transfer the 8292 from CSBS to CACS depending on the state of the 8291 in the system. If the 8291 is in "continuous AH cycling" mode (Aux. Reg. A0 = A1 = 1), then the following procedure should be followed:

1. The master microprocessor stops the continuous AH cycling mode in the 8291;
2. The master reads the 8291 Interrupt Status 1 Register;
3. If the END bit is set, the master sends the TCSY command to the 8292;
4. If the END bit was not set, the master reads the 8291 Data In Register and then waits for another BI interrupt from the 8291. When it occurs, the master sends the 8292 the TCSY command.

If the 8291 is not in AH cycling mode, then the master just waits for a BI interrupt and then sends the TCSY command. After the TCSY command has been issued, the 8292 checks for $\overline{CSBS}$. If $\overline{CSBS}$, then it exits the routine. Otherwise, it then checks the DAV bit in the GPIB status. When DAV becomes false, the 8292 will wait for at least 1.5 μsec. (T10) and then $\overline{ATNO}$ will go low. If DAV does not go low, a TOUT3 error will be generated. If the 8292 successfully takes control, it sets TCI true.

FE — STCNI — Start Counter Interrupts

This command enables the internal counter interrupt. The counter is enabled by the GSEC command.

UTILITY COMMANDS

All these commands are either Read or Write to registers in the 8292. Note that writing to the Error Mask Register and the Interrupt Mask Register are done directly.

E1 — WTOUT — Write To Time Out Register

The byte written to the data bus buffer (with $A_0 = 0$) following this command will determine the time used for the time out function. Since this function is implemented in software, this will not be an accurate time measurement. This feature is enable or disable by the Error Mask Register. No interrupts except for the $\overline{IBFI}$ will be generated upon completion.

E2 — WEVC — Write To Event Counter

The byte written to the data bus buffer (with $A_0 = 0$) following this command will be loaded into the Event Counter Register and the Event Counter Status for byte counting or EOI counting. Only $\overline{IBFI}$ will indicate completion of this command.

E3 — REVC — Read Event Counter Status

This command transfers the contents of the Event Counter into the data bus buffer. A TCI is generated when the data is available in the data bus buffer.

E4 — RERF — Read Error Flag Register

This command transfers the contents of the Error Flag Register into the data bus buffer. A TCI is generated when the data is available.

E5 — RINM — Read Interrupt Mask Register

This command transfers the contents of the Interrupt Mask Register into the data bus buffer. This register is available to the processor so that it does not need to store this information elsewhere. A TCI is generated when the data is available in the data bus buffer.

E6 — RCST — Read Controller Status Register

This command transfers the contents of the Controller Status Register into the data bus buffer and a TCI interrupt is generated.

E7 — RBST — Read GPIB Bus Status Register

This command transfers the contents of the GPIB Bus Status Register into the data bus buffer, and a TCI interrupt is generated when the data is available.

E9 — RTOUT — Read Time Out Status Register

This command transfers the contents of the Time Out Status Register into the data bus buffer, and a TCI interrupt is generated when the data is available.

EA — RERM — Read Error Mask Register

This command transfers the contents of the Error Mask Register to the data bus buffer so that the processor does not need to store this information elsewhere. A TCI interrupt is generated when the data is available.

Interrupt Acknowledge

SYC	[illegible]	SRQ	EV	1	IFCR	1	1
D_7							D_0

Each named bit in an Interrupt Acknowledge (IACK) corresponds to a flag in the Interrupt Status Register. When the 8292 receives this command, it will clear the SPI and the corresponding bits in the Interrupt Status Register. If not all the bits were cleared, then the SPI will be set true again. If the error flag is not acknowledged by the IACK command, then the Error Flag Register will be transferred to the data bus buffer, and a TCI will be generated.

NOTE: XXXX1X11 is an undefined operation or utility command, so no conflict exists between the IACK operation and utility commands.

SYSTEM OPERATION

8292 To Master Processor Interface

Communication between the 8292 and the Master Processor can be either interrupt based communication or based upon polling the interrupt status register in predetermined intervals.

Interrupt Based Communication

Four different interrupts are available from the 8292:

OBFI Output Buffer Full Interrupt
$\overline{\text{IBFI}}$ Input Buffer Not Full Interrupt
TCI Task Completed Interrupt
SPI Special Interrupt

Each of the interrupts is enabled or disabled by a bit in the interrupt mask register. Since OBFI and $\overline{\text{IBFI}}$ are directly connected to the OBF and IBF flags, the master can write a new command to the input data bus buffer as soon as the previous command has been read.

The TCI interrupt is useful when the master is sending commands to the 8292. The pending TCI will be cleared with each new command written to the 8292. Commands sent to the 8292 can be divided into two major groups:

1. Commands that require response back from the 8292 to the master, e.g., reading register.
2. Commands that initiate some action or enable features but do not require response back from the 8292, e.g., enable data bus buffer interrupts.

With the first group, the TCI interrupt will be used to indicate that the required response is ready in the data bus buffer and the master may continue and read it. With the second group, the interrupt will be used to indicate completion of the required task, so that the master may send new commands.

The SPI should be used when immediate information or special events is required (see the Interrupt Status Register).

"Polling Status" Based Communication

When interrupt based communication is not desired, all interrupts can be masked by the interrupt mask register. The communication with the 8292 is based upon sequential poll of the interrupt status register. By testing the OBF and IBF flags, the data bus buffer status is determined while special events are determined by testing the other bits.

Receiving IFC

The IFC pulse defined by the IEEE-488 standard is at least 100 μsec. In this time, all operation on the bus should be aborted. Most important, the current controller (the one that is in charge at that time) should stop sending ATN or EOI. Thus, IFC must externally gate $\overline{\text{CIC}}$ (controller in charge) and $\overline{\text{ATNO}}$ to ensure that this occurs.

Reset and Power Up Procedure

After the 8292 has been reset either by the external reset pin, the device being powered on, or a RST command, the following sequential events will take place:

1. All outputs to the GPIB interface will go high ($\overline{\text{SRQ}}$, $\overline{\text{ATNI}}$, $\overline{\text{IFC}}$, SYC, CLTH, $\overline{\text{ATNO}}$, $\overline{\text{CIC}}$, TCI, SPI, $\overline{\text{EOI}}$, OBFI, $\overline{\text{IBFI}}$, $\overline{\text{DAV}}$, $\overline{\text{REV}}$).
2. The four interrupt outputs (TCI, SPI, OBFI, $\overline{\text{IBFI}}$) and CLTH output will go low.
3. The following registers will be cleared:
   Interrupt Status
   Interrupt Mask
   Error Flag
   Error Mask
   Time Out
   Event Counter (= 256), Counter is disabled.
4. If the 8292 is the system controller, an ABORT command will be executed, the 8292 will become the controller in charge, and it will enter the CACS state.

   If it is not the system controller, it will remain in CIDS.

System Configuration

The 8291 and 8292 must be interfaced to an IEEE-488 bus meeting a variety of specifications including drive capability and loading characteristics. To interface the 8291 and the 8292 without the 8293's, several external gates are required, using a configuration similar to that used in Figure 5.

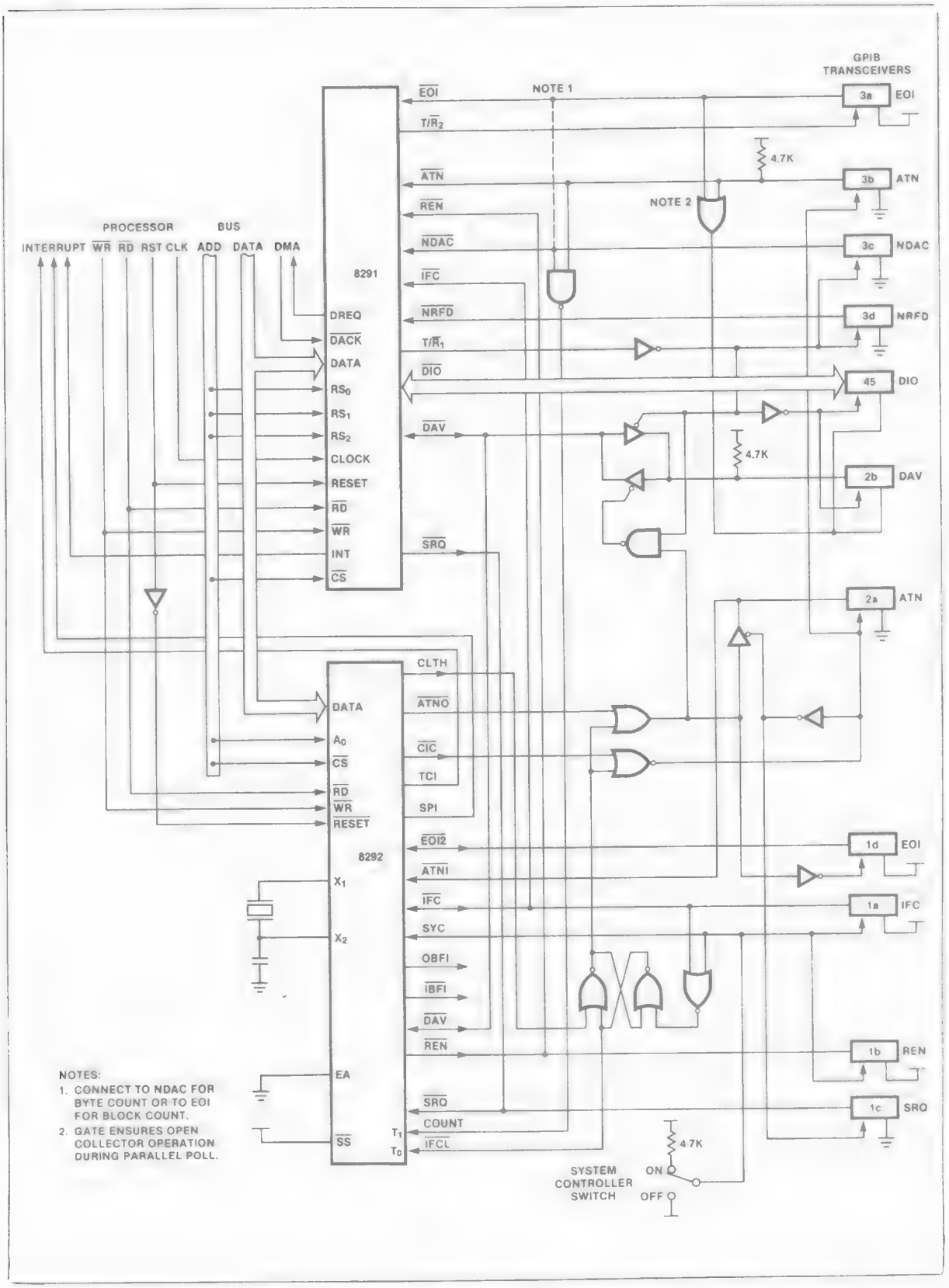

Figure 4. 8291 and 8292 System Configuration

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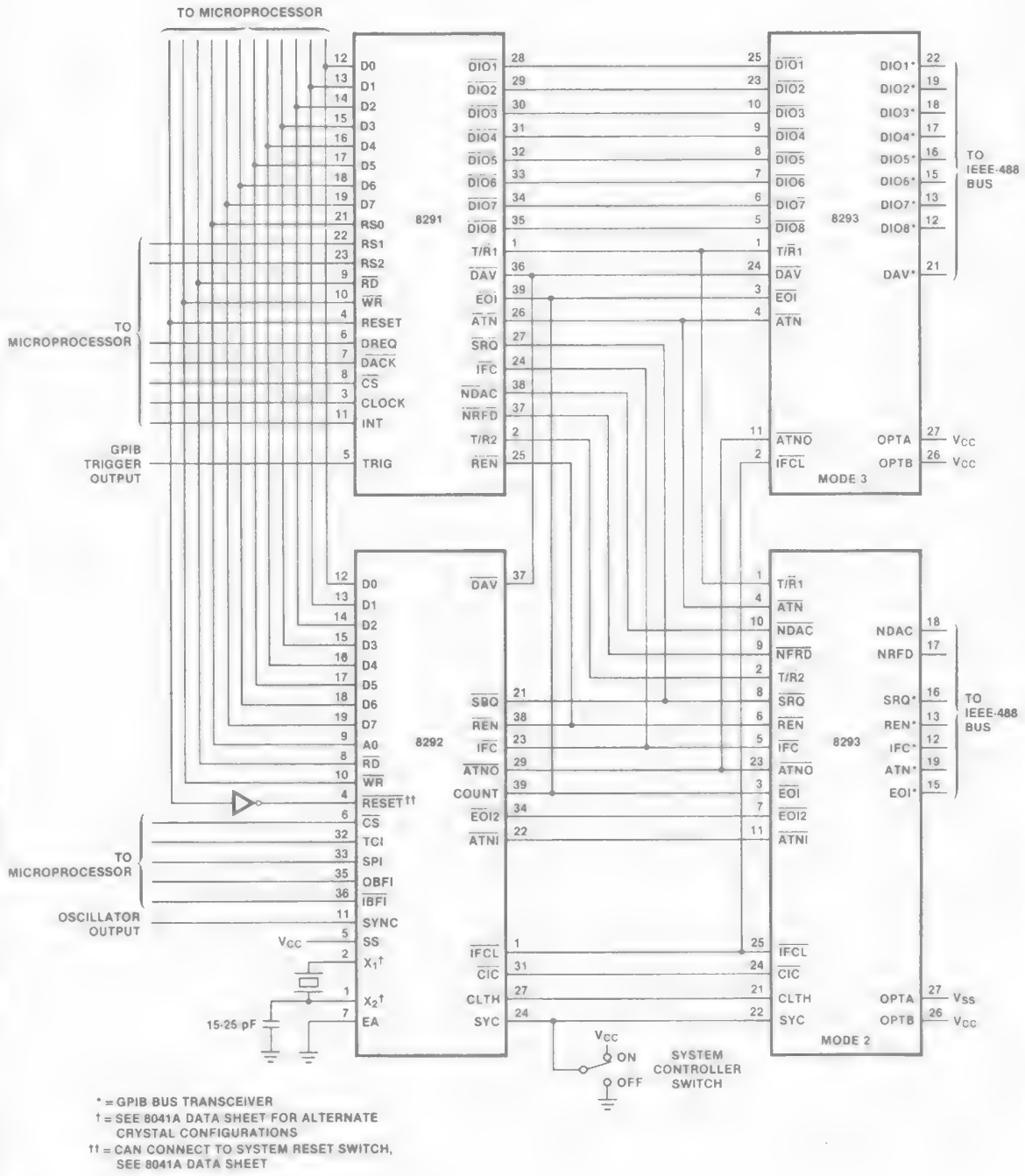


Figure 5. 8291, 8292, and 8293 System Configuration

AFN-00741D

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias.....0°C to 70°C
Storage Temperature.....−65°C to +150°C
Voltage on Any Pin With Respect
to Ground.....0.5V to +7V
Power Dissipation.....1.5 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{SS} = 0V: 8292, V_{CC} = ±5V ±10%)

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
V_{IL1}	Input Low Voltage (All Except X_1, X_2, $\overline{RESET}$)	−0.5	0.8	V	
V_{IL2}	Input Low Voltage (X_1, X_2, $\overline{RESET}$)	−0.5	0.6	V	
V_{IH1}	Input High Voltage (All Except X_1, X_2, $\overline{RESET}$)	2.2	V_{CC}	V	
V_{IH2}	Input High Voltage (X_1, X_2, $\overline{RESET}$)	3.8	V_{CC}	V	
V_{OL1}	Output Low Voltage (D_0-D_7)		0.45	V	I_{OL} = 2.0 mA
V_{OL2}	Output Low Voltage (All Other Outputs)		0.45	V	I_{OL} = 1.6 mA
V_{OH1}	Output High Voltage (D_0-D_7)	2.4		V	I_{OH} = −400 μA
V_{OH2}	Output High Voltage (All Other Outputs)	2.4		V	I_{OH} = −50 μA
I_{IL}	Input Leakage Current (COUNT, $\overline{IFCL}$, $\overline{RD}$, $\overline{WR}$, $\overline{CS}$, A_0)		±10	μA	$V_{SS} \leq V_{IN} \leq V_{CC}$
I_{OZ}	Output Leakage Current (D_0-D_7, High Z State)		±10	μA	$V_{SS} + 0.45 \leq V_{IN} \leq V_{CC}$
I_{LI1}	Low Input Load Current (Pins 21-24, 27-38)		0.5	mA	V_{IL} = 0.8V
I_{LI2}	Low Input Load Current ($\overline{RESET}$)		0.2	mA	V_{IL} = 0.8V
I_{CC}	Total Supply Current		125	mA	Typical = 65 mA
I_{IH}	Input High Leakage Current (Pins 21-24, 27-38)		100	μA	$V_{IN} = V_{CC}$
C_{IN}	Input Capacitance		10	pF	
$C_{I/O}$	I/O Capacitance		20	pF	

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{SS} = 0V: 8292, V_{CC} = +5V ±10%)

DBB READ

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AR}	$\overline{CS}$, A_0 Setup to $\overline{RD}$↓	0		ns	
t_{RA}	$\overline{CS}$, A_0 Hold After $\overline{RD}$↑	0		ns	
t_{RR}	$\overline{RD}$ Pulse Width	250		ns	
t_{AD}	$\overline{CS}$, A_0 to Data Out Delay		225	ns	C_L = 150 pF
t_{RD}	$\overline{RD}$↓ to Data Out Delay		225	ns	C_L = 150 pF
t_{DF}	$\overline{RD}$↑ to Data Float Delay		100	ns	
t_{CY}	Cycle Time	2.5	15	μs	

DBB WRITE

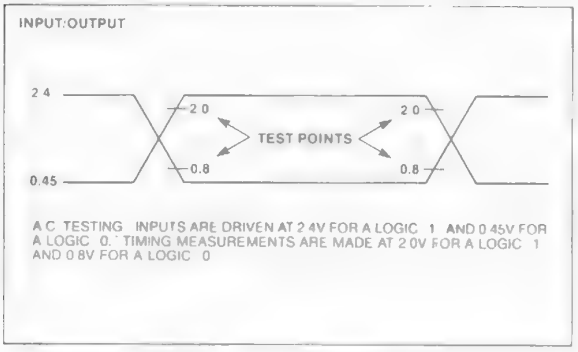
Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AW}	CS, A_0 Setup to WR↓	0		ns	
t_{WA}	CS, A_0 Hold After WR↑	0		ns	
t_{WW}	WR Pulse Width	250		ns	
t_{DW}	Data Setup to WR↑	150		ns	
t_{WD}	Data Hold After WR↓	0		ns	

COMMAND TIMINGS[1,3]

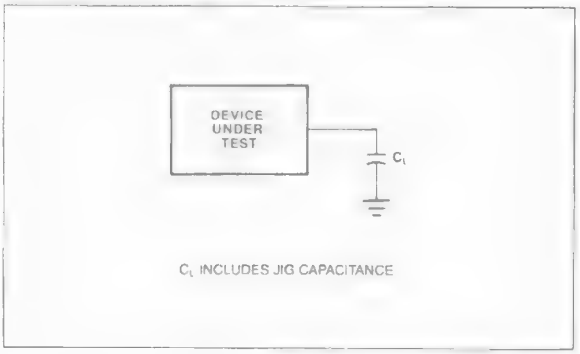
Code	Name	Execution Time	$\overline{IBF}$↑	TCI[2]	SPI	$\overline{ATNO}$	$\overline{CIC}$	$\overline{IFC}$	$\overline{REN}$	$\overline{EOI}$	$\overline{DAV}$	Comments
E1	WTOUT	63	24									
E2	WEVC	63	24									
E3	REVC	71	24	51								
E4	RERF	67	24	47								
E5	RINM	69	24	49								
E6	RCST	97	24	77								
E7	RBST	92	24	72								
E8												
E9	RTOUT	69	24	49								
EA	RERM	69	24	49								
F0	SPCNI	53	24									Count Stops After 39
F1	GIOL	[illegible]	24	70		↑61	↑61					
F2	RST	94	24		↓52							Not System Controller
F2	RST	214	24	192	↓52	↓179	↓174	↓101				System Controller
F3	RSTI	61	24									
F4	GSEC	125	24	107		↑98						
F5	EXPP	75	24						↓53 ↑59	↓55 ↑57		
F6	GTSB	118	24	100		↑91						
F7	SLOC	73	24	55				↓46				
F8	SREM	91	24	73				↓64				
F9	ABORT	155	24	133		↓120	↓115	↓42				
FA	TCNTR	108	24	86		↓71	↓68					
FC	TCAS	92	24	67		↓55						
FD	TCSY	115	24	91		↓80						
FE	STCNI	59	24									Starts Count After 43
PIN	RESET	29	—	↓7	↓7							Not System Controller
X	IACK	116	—		↓73 ↑98							If Interrupt Pending

Notes:
1. All times are multiples of t_{CY} from the 8041A command interrupt.
2. TCI clears after 7 t_{CY} on all commands.
3. ↑ indicates a level transition from low to high, ↓ indicates a high to low transition.

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING LOAD CIRCUIT



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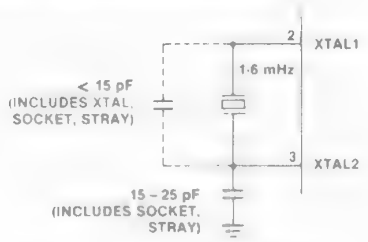
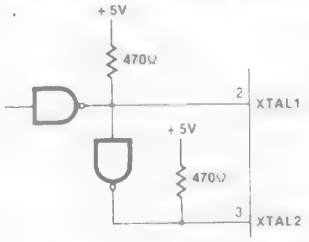
CLOCK DRIVER CIRCUITS

CRYSTAL OSCILLATOR MODE



CRYSTAL SERIES RESISTANCE SHOULD BE <75Ω AT 6 MHz; <180Ω AT 3.6 MHz

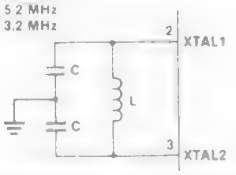
DRIVING FROM EXTERNAL SOURCE



BOTH XTAL1 AND XTAL2 SHOULD BE DRIVEN
RESISTORS TO V_{CC} ARE NEEDED TO ENSURE $V_{IH} = 3.8V$
IF TTL CIRCUITRY IS USED

LC OSCILLATOR MODE

L	C	NOMINAL f
45 μH	20 pF	5.2 MHz
120 μH	20 pF	3.2 MHz



$$f = \frac{1}{2\pi\sqrt{LC'}}$$

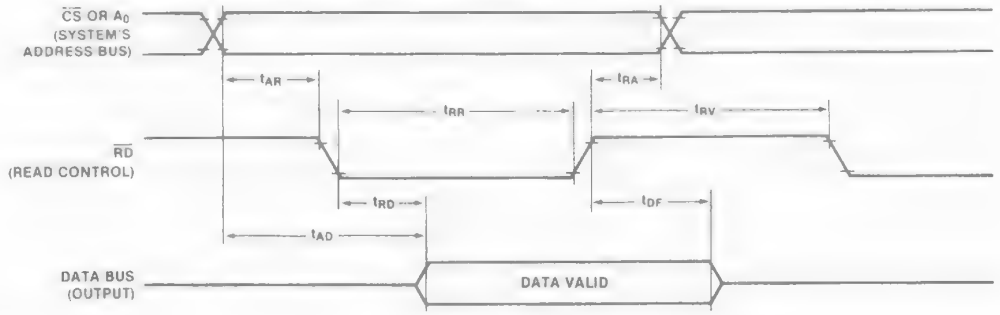
$$C' = \frac{C + 3C_{PP}}{2}$$

$C_{PP} \approx 5 - 10$ pF PIN-TO-PIN CAPACITANCE

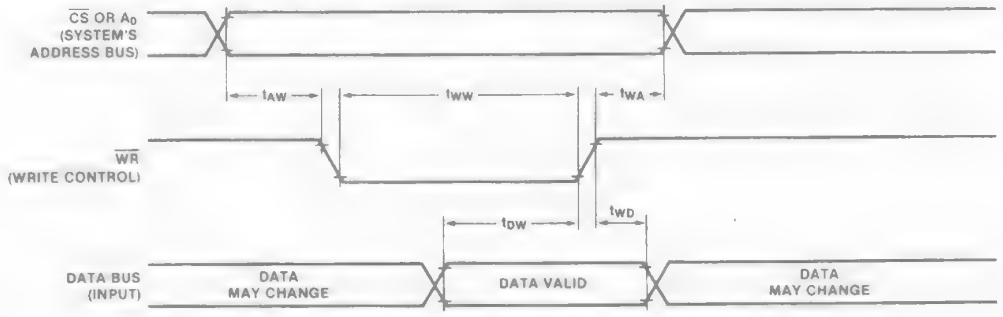
EACH C SHOULD BE APPROXIMATELY 20 pF, INCLUDING STRAY CAPACITANCE

WAVEFORMS

READ OPERATION—DATA BUS BUFFER REGISTER



WRITE OPERATION — DATA BUS BUFFER REGISTER



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APPENDIX

The following tables and state diagrams were taken from the IEEE Standard Digital Interface for Programmable Instrumentation, IEEE Std. 488-1978. This document is the official standard for the GPIB bus and can be purchased from IEEE, 345 East 47th St., New York, NY 10017.

C MNEMONICS

Messages	Interface States
pon = power on	CIDS = controller idle state
rsc = request system control	CADS = controller addressed state
rpp = request parallel poll	CTRS = controller transfer state
gts = go to standby	CACS = controller active state
tca = take control asynchronously	CPWS = controller parallel poll wait state
tcs = take control synchronously	CPPS = controller parallel poll state
sic = send interface clear	CSBS = controller standby state
sre = send remote enable	CSHS = controller standby hold state
IFC = interface clear	CAWS = controller active wait state
ATN = attention	CSWS = controller synchronous wait state
TCT = take control	CSRS = controller service requested state
	CSNS = controller service not requested state
	SNAS = system control not active state
	SACS = system control active state
	SRIS = system control remote enable idle state
	SRNS = system control remote enable not active state
	SRAS = system control remote enable active state
	SIIS = system control interface clear idle state
	SINS = system control interface clear not active state
	SIAS = system control interface clear active state
	(ACDS) = accept data state (AH function)
	(ANRS) = acceptor not ready state (AH function)
	(SDYS) = source delay state (SH function)
	(STRS) = source transfer state (SH function)
	(TADS) = talker addressed state (T function)

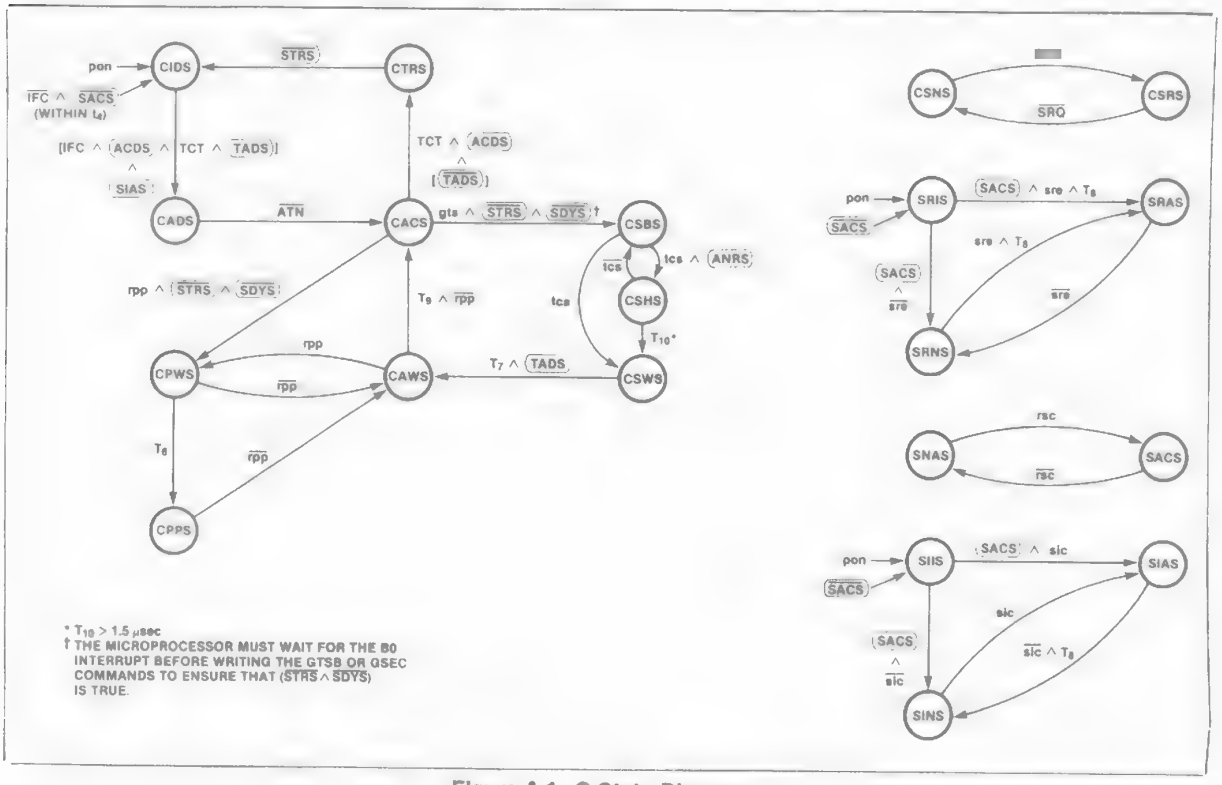

Figure A.1. C State Diagram

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REMOTE MESSAGE CODING

Mnemonic	Message Name		TYPE	CLASS	Bus Signal Line(s) and Coding That Asserts the True Value of the Message													
					DIO8	7	6	5	4	3	2	DIO1	ATN DAV	NRFD NDAC	ATN	EOI	SRQ	IFC	REN
ACG	Addressed Command Group		M	AC	Y	0	0	0	X	X	X	X	XXX		1	X	X	X	X
ATN	Attention		U	UC	X	X	X	X	X	X	X	X	XXX		1	X	X	X	X
DAB	Data Byte	(Notes 1, 9)	M	DD	D8	D7	D6	D5	D4	D3	D2	D1	XXX		0	X	X	X	X
DAC	Data Accepted		U	HS	X	X	X	X	X	X	X	X	XX0		X	X	X	X	X
DAV	Data Valid		U	HS	X	X	X	X	X	X	X	X	1XX		X	X	X	X	X
DCL	Device Clear		M	UC	Y	0	0	1	0	1	0	0	XXX		1	X	X	X	X
END	End		U	ST	X	X	X	X	X	X	X	X	XXX		0	1	X	X	X
EOS	End of String	(Notes 2, 9)	M	DD	E8	E7	E6	E5	E4	E3	E2	E1	XXX		0	X	X	X	X
GET	Group Execute Trigger		M	AC	Y	0	0	0	1	0	0	0	XXX		1	X	X	X	X
GTL	Go to Local		M	AC	Y	0	0	0	0	0	0	1	XXX		1	X	X	X	X
IDY	Identify		U	UC	X	X	X	X	X	X	X	X	XXX		X	1	X	X	X
IFC	Interface Clear		U	UC	X	X	X	X	X	X	X	X	XXX		X	X	X	1	X
LAG	Listen Address Group		M	AD	Y	0	1	X	X	X	X	X	XXX		1	X	X	X	X
LLO	Local Lock Out		M	UC	Y	0	0	1	0	0	0	1	XXX		1	X	X	X	X
MLA	My Listen Address	(Note 3)	M	AD	Y	0	1	L5	L4	L3	L2	L1	XXX		1	X	X	X	X
MTA	My Talk Address	(Note 4)	M	AD	Y	1	0	T5	T4	T3	T2	T1	XXX		1	X	X	X	X
MSA	My Secondary Address	(Note 5)	M	SE	Y	1	1	S5	S4	S3	S2	S1	XXX		1	X	X	X	X
NUL	Null Byte		M	DD	0	0	0	0	0	0	0	0	XXX		X	X	X	X	X
OSA	Other Secondary Address		M	SE	(OSA = SCG ∧ $\overline{MSA}$)														
OTA	Other Talk Address		M	AD	(OTA = TAG ∧ $\overline{MTA}$)														
PCG	Primary Command Group		M	—	(PCG = ACG ∨ UCG ∨ LAG ∨ TAG)														
PPC	Parallel Poll Configure		M	AC	Y	0	0	0	0	1	0	1	XXX		1	X	X	X	X
PPE	Parallel Poll Enable	(Note 6)	M	SE	Y	1	1	0	S	P3	P2	P1	XXX		1	X	X	X	X
PPD	Parallel Poll Disable	(Note 7)	M	SE	Y	1	1	1	D4	D3	D2	D1	XXX		1	X	X	X	X
PPR1	Parallel Poll Response 1	(Note 10)	U	ST	X	X	X	X	X	X	X	1	XXX		1	1	X	X	X
PPR2	Parallel Poll Response 2	(Note 10)	U	ST	X	X	X	X	X	X	1	X	XXX		1	1	X	X	X
PPR3	Parallel Poll Response 3	(Note 10)	U	ST	X	X	X	X	X	1	X	X	XXX		1	1	X	X	X
PPR4	Parallel Poll Response 4	(Note 10)	U	ST	X	X	X	X	1	X	X	X	XXX		1	1	X	X	X
PPR5	Parallel Poll Response 5	(Note 10)	U	ST	X	X	X	1	X	X	X	X	XXX		1	1	X	X	X
PPR6	Parallel Poll Response 6	(Note 10)	U	ST	X	X	1	X	X	X	X	X	XXX		1	1	X	X	X
PPR7	Parallel Poll Response 7	(Note 10)	U	ST	X	1	X	X	X	X	X	X	XXX		1	1	X	X	X
PPR8	Parallel Poll Response 8	(Note 10)	U	ST	1	X	X	X	X	X	X	X	XXX		1	1	X	X	X
PPU	Parallel Poll Unconfigure		M	UC	Y	0	0	1	0	1	0	1	XXX		1	X	X	X	X
REN	Remote Enable		U	UC	X	X	X	X	X	X	X	X	XXX		X	X	X	X	1
RFD	Ready for Data		U	HS	X	X	X	X	X	X	X	X	X0X		X	X	X	X	X
RQS	Request Service	(Note 9)	U	ST	X	1	X	X	X	X	X	X	XXX		0	X	X	X	X
SCG	Secondary Command Group		M	SE	Y	1	1	X	X	X	X	X	XXX		1	X	X	X	X
SDC	Selected Device Clear		M	AC	Y	0	0	0	0	1	0	0	XXX		1	X	X	X	X
SPD	Serial Poll Disable		M	UC	Y	0	0	1	1	0	0	1	XXX		1	X	X	X	X
SPE	Serial Poll Enable		M	UC	Y	0	0	1	1	0	0	0	XXX		1	X	X	X	X
SRQ	Service Request		U	ST	X	X	X	X	X	X	X	X	XXX		X	X	1	X	X
STB	Status Byte	(Notes 8, 9)	M	ST	S8	X	S6	S5	S4	S3	S2	S1	XXX		0	X	X	X	X
TCT	Take Control		M	AC	Y	0	0	0	1	0	0	1	XXX		1	X	X	X	X
TAG	Talk Address Group		M	AD	Y	1	0	X	X	X	X	X	XXX		1	X	X	X	X
UCG	Universal Command Group		M	UC	Y	0	0	1	X	X	X	X	XXX		1	X	X	X	X
UNL	Unlisten		M	AD	Y	0	1	1	1	1	1	1	XXX		1	X	X	X	X
UNT	Untalk	(Note 11)	M	AD	Y	1	0	1	1	1	1	1	XXX		1	X	X	X	X

The 1/0 coding on ATN when sent concurrent with multiline messages has been added to this revision for interpretive convenience.

NOTES:

1. D1-D8 specify the device dependent data bits.
2. E1-E8 specify the device dependent code used to indicate the EOS message.
3. L1-L5 specify the device dependent bits of the device's listen address.
4. T1-T5 specify the device dependent bits of the device's talk address.
5. S1-S5 specify the device dependent bits of the device's secondary address.
6. S specifies the sense of the PPR.

   Response = $\overline{S \oplus ist}$

P1-P3 specify the PPR message to be sent when a parallel poll is executed.

P3	P2	P1	PPR Message
0	0	0	PPR1
.	.	.	.
.	.	.	.
.	.	.	.
1	1	1	PPR8

7. D1-D4 specify don't-care bits that shall not be decoded by the receiving device. It is recommended that all zeroes be sent.
8. S1-S6, S8 specify the device dependent status. (DIO7 is used for the RQS message.)
9. The source of the message on the ATN line is always the C function, whereas the messages on the DIO and EOI lines are enabled by the T function.
10. The source of the messages on the ATN and EOI lines is always the C function, whereas the source of the messages on the DIO lines is always the PP function.
11. This code is provided for system use, see 6.3.

PRELIMINARY

8293
GPIB TRANSCEIVER

- Nine Open-collector or Three-state Line Drivers
- 48 mA Sink Current Capability on Each Line Driver
- Nine Schmitt-type Line Receivers
- High Capacitance Load Drive Capability
- Single 5V Power Supply
- 28-Pin Package
- Low Power HMOS Design
- On-chip Decoder for Mode Configuration
- Power Up/Power Down Protection to Prevent Disrupting the IEEE Bus
- Connects with the 8291A and 8292 to Form an IEEE Standard 488 Interface Talker/Listener/Controller with no Additional Components
- Only Two 8293's Required per GPIB Interface
- On-Chip IEEE-488 Bus Terminations

The Intel® 8293 GPIB Transceiver is a high-current, non-inverting buffer chip designed to interface the 8291A GPIB Talker/Listener, or the 8291A/8292 GPIB Talker/Listener/Controller combination, to the IEEE Standard 488-1978 Instrumentation Interface Bus. Each GPIB interface would contain two 8293 Bus Transceivers. In addition, the 8293 can also be used as a general-purpose bus driver.

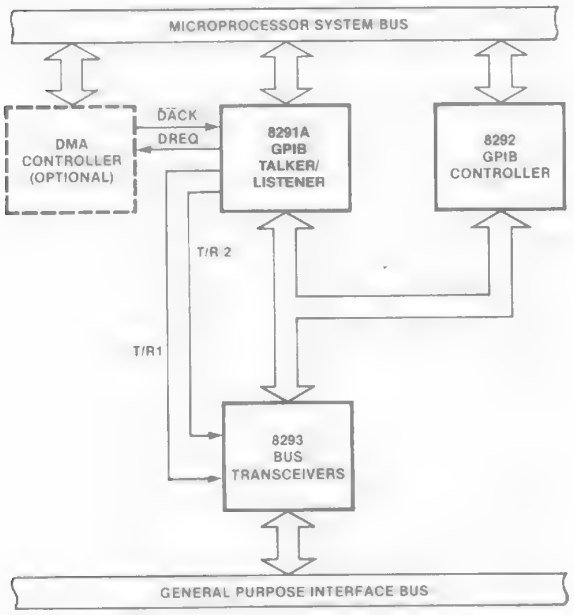

Figure 1. 8291A, 8292, 8293 Block Diagram

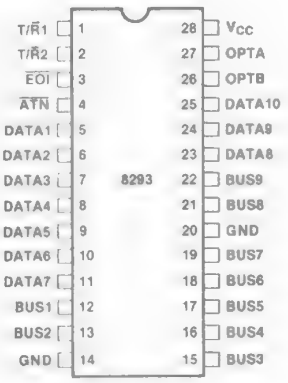

Figure 2. Pin Configuration

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
BUS1-BUS9	12, 13, 15–19, 21, 22	I/O	**GPIB Lines, GPIB Side:** These are the IEEE-488 bus interface driver/receivers, or TTL-compatible inputs on the 8291A/8292 side, depending on the mode used. Their use is programmed by the two mode select pins, OPTA and OPTB.
DATA1-DATA10	5–11, 23–25	I/O	**GPIB Lines, 8291A/92 Side:** These are the pins to be connected to the 8291A and 8292 to interface with the GPIB. Their use is programmed by the two mode select pins, OPTA and OPTB. All these pins are TTL compatible.
T/$\overline{R}$1	1	I	**Transmit Receive 1:** This pin controls the direction for NDAC, NRFD, DAV, and DIO1-DIO8. Input is TTL compatible.
T/$\overline{R}$2	2	I	**Transmit Receive 2:** This pin controls the direction for EOI. Input is TTL compatible.
$\overline{EOI}$	3	I/O	**End Or Identify:** This pin indicates the end of a multiple byte transfer or, in conjunction with ATN, addresses the device during a polling sequence. It connects to the 8291A and is switched between transmit and receive by T/$\overline{R}$2. This pin is TTL compatible.
$\overline{ATN}$	4	O	**Attention:** This pin is used by the 8291A to monitor the GPIB ATN control line. It specifies how data on the DIO lines is to be interpreted. This output is TTL compatible.
OPTA OPTB	27 26	I I	**Mode Select:** These two pins are to control the function of the 8293. A truth table of how they program the various modes is in Table 2.
V_{CC}	28	P.S.	**Voltage:** Positive power supply (5V ± 10%).
GND	14, 20	P.S.	**Ground:** Circuit ground.

Table 2. 8293 Mode Selection Pin Mapping

Pin Name	Pin No.	IEEE Implementation Name			
		Mode 0	Mode 1	Mode 2	Mode 3
OPTA	27	0	1	0	1
OPTB	26	0	0	1	1
DATA1	5	$\overline{IFC}$	$\overline{DIO8}$	$\overline{IFC}$	$\overline{DIO8}$
BUS1	12	IFC*	DIO8*	IFC*	DIO8*
DATA2	6	$\overline{REN}$	$\overline{DIO7}$	$\overline{REN}$	$\overline{DIO7}$
BUS2	13	REN*	DIO7*	REN*	DIO7*
DATA3	7	NC	$\overline{DIO6}$	$\overline{EOI2}$	$\overline{DIO6}$
BUS3	15	EOI*	DIO6*	EOI*	DIO6*
DATA4	8	$\overline{SRQ}$	$\overline{DIO5}$	$\overline{SRQ}$	$\overline{DIO5}$
BUS4	16	SRQ*	DIO5*	SRQ*	DIO5*
DATA5	9	$\overline{NRFD}$	$\overline{DIO4}$	$\overline{NRFD}$	$\overline{DIO4}$
BUS5	17	NRFD*	DIO4*	NRFD*	DIO4*
DATA6	10	$\overline{NDAC}$	$\overline{DIO3}$	$\overline{NDAC}$	$\overline{DIO3}$
BUS6	18	NDAC*	DIO3*	NDAC*	DIO3*
DATA7	11	T/$\overline{R}$IO1	NC	$\overline{ATNI}$	$\overline{ATNO}$
DATA8	23	T/$\overline{R}$IO2	$\overline{DIO2}$	$\overline{ATNO}$	$\overline{DIO2}$
BUS7	19	ATN*	DIO2*	ATN*	DIO2*
DATA9	24	$\overline{GIO1}$	$\overline{DAV}$	$\overline{CIC}$	$\overline{DAV}$
BUS8	21	GIO1*	DAV*	CLTH	DAV*
DATA10	25	$\overline{GIO2}$	$\overline{DIO1}$	$\overline{IFCL}$	$\overline{DIO1}$
BUS9	22	GIO2*	DIO1*	SYC	DIO1*
T/$\overline{R}$1	1	T/$\overline{R}$1	T/$\overline{R}$1	T/$\overline{R}$1	T/$\overline{R}$1
T/$\overline{R}$2	2	T/$\overline{R}$2	NC	T/$\overline{R}$2	$\overline{IFCL}$
$\overline{EOI}$	3	$\overline{EOI}$	$\overline{EOI}$	$\overline{EOI}$	$\overline{EOI}$
$\overline{ATN}$	4	$\overline{ATN}$	$\overline{ATN}$	$\overline{ATN}$	$\overline{ATN}$

***Note:** These pins are the IEEE-488 bus non-inverting driver/receivers. They include all the bus terminations required by the Standard and may be connected directly to the GPIB bus connector.

GENERAL DESCRIPTION

The 8293 is a bidirectional transceiver. It was designed to interface the Intel 8291A GPIB Talker/Listener and the Intel® 8292 GPIB Controller to the IEEE Standard 488-1978 Instrumentation Bus (also referred to as the GPIB). The Intel GPIB Transceiver meets or exceeds all of the electrical specifications defined in the IEEE Standard 488-1978, Section 3.3–3.5, including the bus termination specifications.

The 8293 can be hardware programmed to one of four modes of operation. These modes allow the 8293 to be configured to support both a Talker/Listener/Controller environment and a Talker/Listener environment. In addition, the 8293 can be used as a general-purpose, three-state (push-pull) of open-collector bus transceiver with nine receiver/drivers. Two modes each are used to support a Talker/Listener (see Figure 3) and a Talker/Listener/Controller environment (see Figure 4). Mode 1 is used in general-purpose environments.

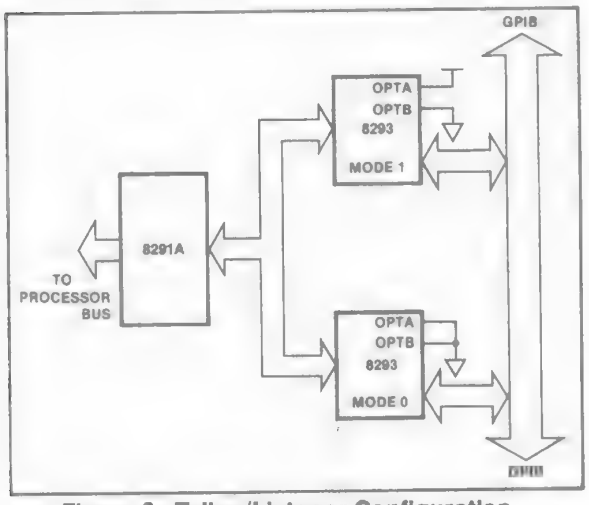

Figure 3. Talker/Listener Configuration

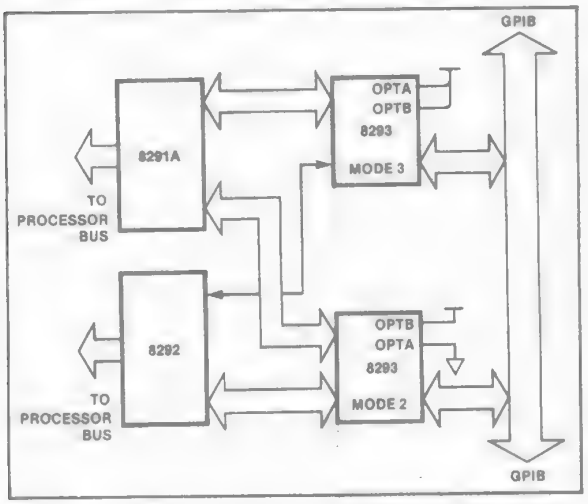

Figure 4. Talker/Listener/Controller Configuration

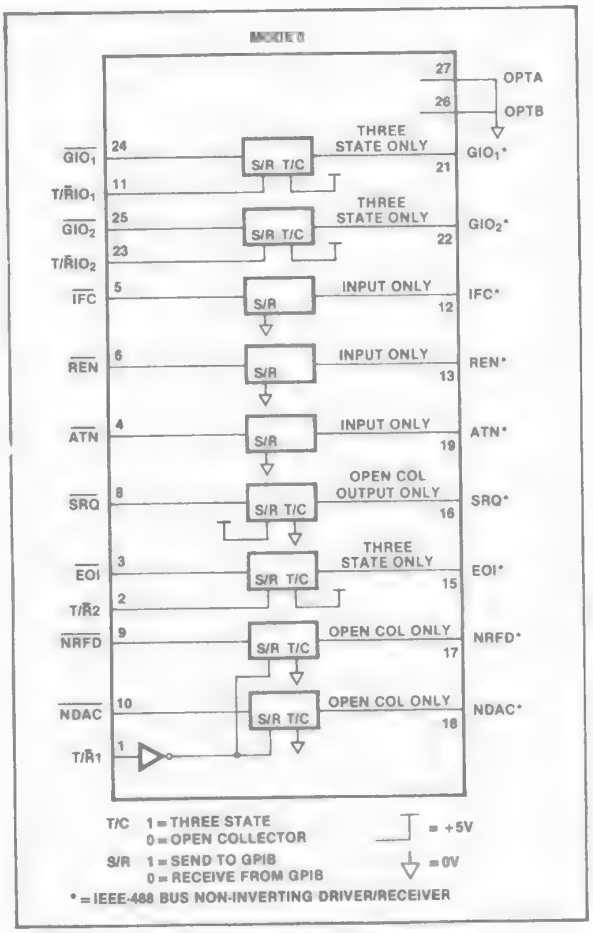

Figure 5. Talker/Listener Control Configuration

Table 3. Mode 0 Pin Description

Symbol	Pin No.	Type	Name and Function
T/$\overline{R}$1	1	I	**Transmit Receive 1** Direction control for NDAC and NRFD. If T/R1 is high, then NDAC* and NRFD* are receiving. Input is TTL compatible.
$\overline{NDAC}$	10	I/O	**Not Data Accepted:** Processor GPIB bus handshake control line; used to indicate the condition of acceptance of data by device(s). It is TTL compatible.
NDAC*	18	I/O	**Not Data Accepted:** IEEE GPIB bus handshake control line. When an input, it is a TTL compatible Schmitt-trigger. When an output, it is an open-collector driver with 48 mA sinking capability.
$\overline{NRFD}$	[illegible]	I/O	**Not Ready For Data:** Processor GPIB handshake control line; used to indicate the condition of readiness of device(s) to accept data. This pin is TTL compatible.

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Table 3. Mode 0 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
NRFD*	17	I/O	**Not Ready For Data:** IEEE GPIB bus handshake control line. When an input, it is a TTL compatible Schmitt-trigger. When an output, it is an open-collector driver with a 48 mA current sinking capability.
T/$\overline{R}$2	2	I	**Transmit Receive 2:** Direction control for EOI. If T/R2 is high, EOI* is sending. Input is TTL compatible.
$\overline{EOI}$	3	I/O	**End Or Identify:** Processor GPIB bus control line; is used by a talker to indicate the end of a multiple byte transfer. This pin is TTL compatible.
EOI*	15	I/O	**End Or Identify:** IEEE GPIB bus control line; is used by a talker to indicate the end of a multiple byte transfer. This pin is a three-state (push-pull) driver capable of sinking 48 mA and a TTL compatible receiver with hysteresis.
$\overline{SRQ}$	[illegible]	I	**Service Request:** Processor GPIB bus control line; used by a device to indicate the need for service and to request an interruption of the current sequence of events on the GPIB. It is a TTL compatible input.
SRQ*	16	O	**Service Request:** IEEE GPIB bus control line; it is an open collector driver capable of sinking 48 mA.
$\overline{REN}$	6	O	**Remote Enable:** Processor GPIB bus control line; used by a controller (in conjunction with other messages) to select between two alternate sources of device programming data (remote or local control). This output is TTL compatible.
REN*	13	I	**Remote Enable:** IEEE GPIB bus control line. This input is a TTL compatible Schmitt-trigger.
$\overline{ATN}$	4	O	**Attention:** Processor GPIB bus control line; used by the 8291 to determine how data on the DIO signal lines are to be interpreted. This is a TTL compatible output.
ATN*	19	I	**Attention:** IEEE GPIB bus control line; this input is a TTL compatible Schmitt-trigger.
$\overline{IFC}$	5	O	**Interface Clear:** Processor GPIB bus control line; used by a controller to place the interface system into a known quiescent state. It is a TTL compatible output.

Symbol	Pin No.	Type	Name and Function
IFC*	12	I	**Interface Clear:** IEEE GPIB bus control line. This input is a TTL compatible Schmitt-trigger.
T/$\overline{R}$IO1 T/$\overline{R}$IO2	11 23	I I	**Transmit Receive General IO:** Direction control for the two spare transceivers. These pins are TTL compatible.
$\overline{GIO1}$ $\overline{GIO2}$	[illegible] 25	I/O I/O	**General IO:** This is the TTL side of the two spare transceivers. These pins are TTL compatible.
GIO1* GIO2*	21 22	I/O I/O	**General IO:** These are spare three-state (push-pull) drivers/Schmitt-trigger receivers. The drivers can sink 48 mA.

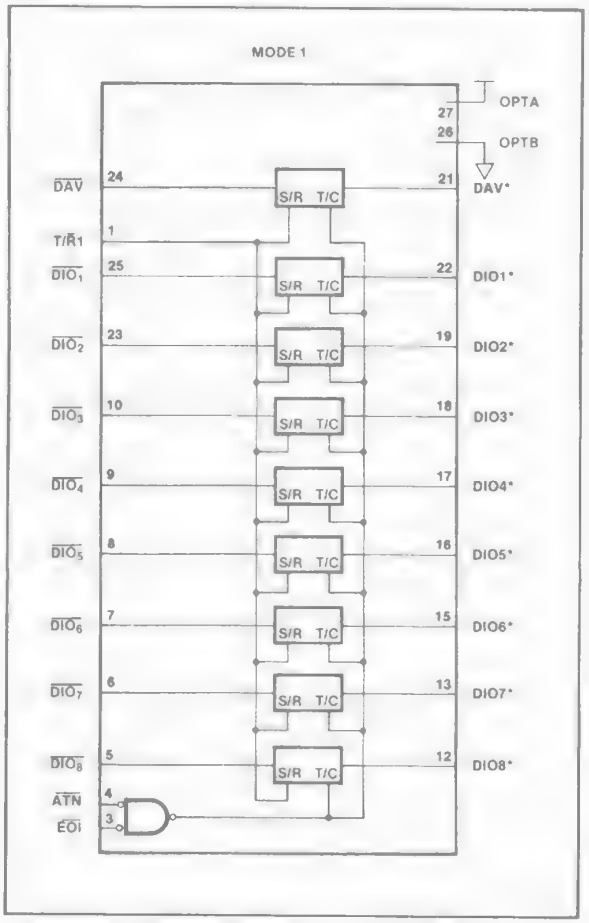

Figure 6. Talker/Listener Data Configuration

Table 4. Mode 1 Pin Description

Symbol	Pin No.	Type	Name and Function
T/$\overline{R1}$	1	I	**Transmit Receive 1:** Controls the direction for DAV and the DIO lines. If T/$\overline{R1}$ is high, then all these lines are sending information to the IEEE GPIB lines. This input is TTL compatible.
$\overline{EOI}$ $\overline{ATN}$	3 4	I I	**End Of Sequence And Attention:** Processor GPIB control lines. These two control signals are ANDed together to determine whether all the transceivers in the 8293 are three-state (push-pull) or open-collector. When both signals are low (true), then the controller is performing a parallel poll and the transceivers are all open-collector. These inputs are TTL compatible.
$\overline{DAV}$	24	I/O	**Data Valid:** Processor GPIB bus handshake control line; used to indicate the condition (availability and validity) of information on the DIO lines. It is TTL compatible.
DAV*	21	I/O	**Data Valid:** IEEE GPIB bus handshake control line. When an input, it is a TTL compatible Schmitt-trigger. When DAV* is an output, it can sink 48 mA.
$\overline{DIO1}$- $\overline{DIO8}$	25, 23, 10, 9, 8, 7, 6, 5	I/O	**Data Input/Output:** Processor GPIB bus data lines; used to carry message and data bytes in a bit-parallel byte-serial form controlled by the three handshake signals. These lines are TTL compatible.
DIO1*- DIO8*	22, 19, 18, 17, 16, 15, 13, 12	I/O	**Data Input/Output:** IEEE GPIB bus data lines. They are TTL compatible Schmitt-triggers when used for input and can sink 48 mA when used for output. See $\overline{ATN}$ and $\overline{EOI}$ description for output mode.

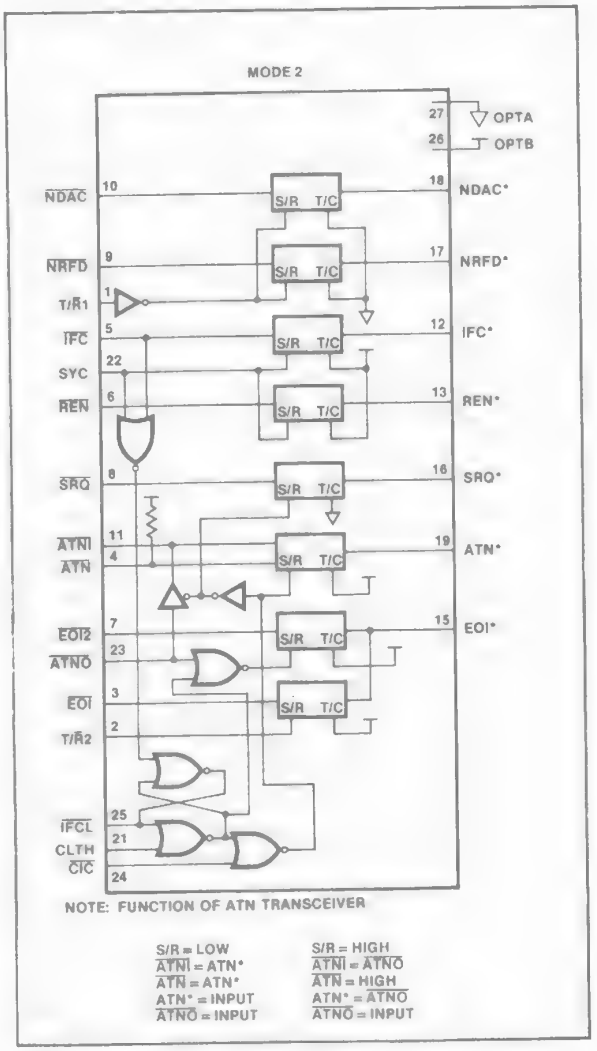

Figure 7. Talker/Listener/Controller Control Configuration

Table 5. Mode 2 Pin Description

Symbol	Pin No.	Type	Name and Function
T/$\overline{R1}$	1	I	**Transmit Receive 1:** Direction control for NDAC and NRFD. If T/$\overline{R1}$ is high, then NDAC and NRFD are receiving. Input is TTL compatible.
$\overline{NDAC}$	10	I/O	**Not Data Accepted:** Processor GPIB bus handshake control line; used to indicate the condition of acceptance of data by device(s). This pin is TTL compatible.
NDAC*	18	I/O	**Not Data Accepted:** IEEE GPIB bus handshake control line. It is a TTL compatible Schmitt-trigger when used for input and an open-collector driver with a 48 mA current sink capability when used for output.
$\overline{NRFD}$	9	I/O	**Not Ready For Data:** Processor GPIB bus handshake control line; used to indicate the condition of readiness of device(s) to accept data. This pin is TTL compatible.
NRFD*	17	I/O	**Not Ready For Data:** IEEE GPIB bus handshake control line. It is a TTL compatible Schmitt-trigger when used for input and an open-collector driver with a 48 mA current sink capability when used for output.
SYC[1]	22	I	**System Controller:** Used to monitor the system controller switch and control the direction for IFC and REN. This pin is a TTL compatible input.
$\overline{REN}$	[illegible]	I/O	**Remote Enable:** Processor GPIB control line; used by the active controller (in conjunction with other messages) to select between two alternate sources of device programming data (remote or local control). This pin is TTL compatible.
REN*	13	I/O	**Remote Enable:** IEEE GPIB bus control line. When used as an input, this is a TTL compatible Schmitt-trigger. When an output, it is a three-state driver with a 48 mA current sinking capability.
$\overline{IFC}$	5	I/O	**Interface Clear:** Processor GPIB bus control line; used by the active controller to place the interface system into a known quiescent state. This pin is TTL compatible.
IFC*	12	I/O	**Interface Clear:** IEEE GPIB control line. This is a TTL compatible Schmitt-trigger when used for input and a three-state driver capable of sinking 48 mA current when used for output.
$\overline{CIC}$	24	I	**Controller In Charge:** Used to control the direction of the SRQ and to indicate that the 8292 is in charge of the bus. $\overline{CIC}$ is a TTL compatible input.
CLTH[1]	21	I	**Clear Latch:** Used to clear the IFC Received latch after it has been recognized by the 8292. Normally low (except after a hardware reset). It will be pulsed high when IFC Received is recognized by the 8292. This input is TTL compatible.
$\overline{IFCL}$	25	O	**IFC Received Latch:** The 8292 monitors the IFC line when it is not the active controller through this pin.
$\overline{SRQ}$	[illegible]	I/O	**Service Request:** Processor GPIB control line; indicates the need for attention and requests the active controller to interrupt the current sequence of events on the GPIB bus. This pin is TTL compatible.
SRQ*	16	I/O	**Service Request:** IEEE GPIB bus control line. When used as an input, this pin is a TTL compatible Schmitt-trigger. When used as an output, it is an open-collector driver with a 48 mA current sinking capability.
T/$\overline{R2}$	[illegible]	I	**Transmit Receive 2:** Controls the direction for EOI. This input is TTL compatible.
$\overline{ATNO}$	23	I	**Attention Out:** Processor GPIB bus control line; used by the 8292 for ATN control of the IEEE bus during "take control synchronously" operations. A low on this input causes ATN to be asserted if $\overline{CIC}$ indicates that this 8292 is in charge. $\overline{ATNO}$ is a TTL compatible input.
$\overline{ATNI}$	11	O	**Attention In:** Processor GPIB bus control line; used by the 8292 to monitor the ATN line. This output is TTL compatible.
$\overline{ATN}$	[illegible]	O	**Attention:** Processor GPIB bus control line; used by the 8292 to monitor the ATN line. This output is TTL compatible.
ATN*	19	I/O	**Attention:** IEEE GPIB bus control line; used by a controller to specify how data on the DIO signal lines are to be interpreted and which devices must respond to data. When used as an output, this pin is a three-state driver capable of sinking 48 mA current. As an input, it is a TTL compatible Schmitt-trigger.
$\overline{EOI2}$	7	I/O	**End Or Identify 2:** Processor GPIB bus control line; used in conjunction with ATN by the active controller (the 8292) to execute a polling sequence. This pin is TTL compatible.
$\overline{EOI}$	[illegible]	I/O	**End Or Identify:** Processor GPIB bus control line; used by a talker to indicate the end of a multiple byte transfer sequence. This pin is TTL compatible.

NOTES:

1. V_{IL3} is guaranteed at 1.1V on these inputs to accommodate the high current-sourcing capability of these pins during a low input in Mode 2.

Table 5. Mode 2 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
EOI*	15	I/O	**End Or Identify:** IEEE GPIB bus control line; used by a talker to indicate the end of a multiple byte transfer sequence or, by a controller in conjunction with ATN, to execute a polling sequence. When an output, this pin can sink 48 mA current. When an input, it is a TTL compatible Schmitt-trigger.

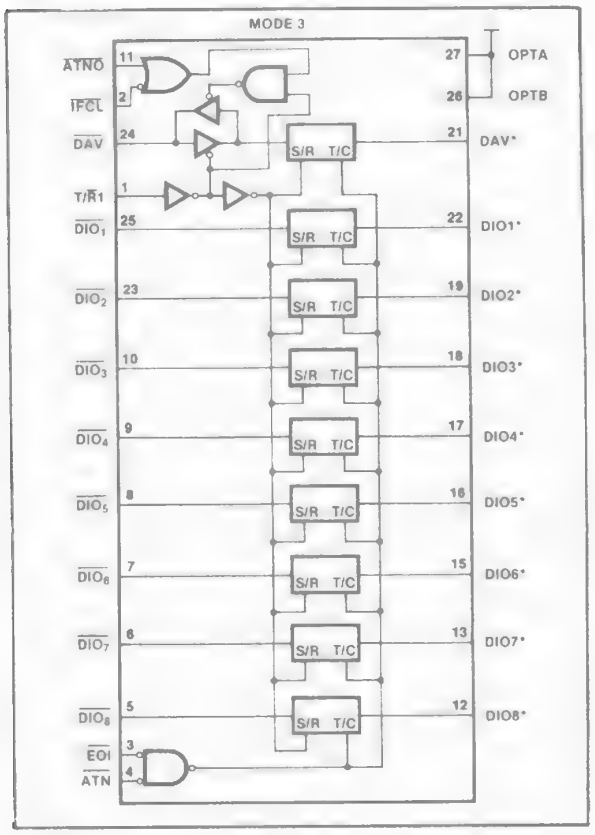

Figure 8. Talker/Listener/Controller Data Configuration

Table 6. Mode 3 Pin Description

Symbol	Pin No.	Type	Name and Function
T/$\overline{R}$1	1	I	**Transmit Receive 1:** Controls the direction for DAV and the DIO lines. If T/$\overline{R}$1 is high, then all these lines are sending information to the IEEE GPIB lines. This input is TTL compatible.
$\overline{EOI}$ $\overline{ATN}$	3 [illegible]	I I	**End Of Sequence and Attention:** Processor GPIB control lines. These two control lines are ANDed together to determine whether all the transceivers in the 8293 are push-pull or open-collector. When both signals are low (true), then the controller is performing a parallel poll and the transceivers are all open-collector. These inputs are TTL compatible.
$\overline{ATNO}$	11	I	**Attention Out:** Processor GPIB control line; used by the 8292 during "take control synchronously" operations. This pin is TTL compatible.
$\overline{IFCL}$	[illegible]	I	**Interface Clear Latched:** Used to make DAV received after the system controller asserts IFC. This input is TTL compatible.
$\overline{DAV}$	24	I/O	**Data Valid:** Processor GPIB handshake control line; used to indicate the condition (availability and validity) of information on the DIO signals. This pin is TTL compatible.
DAV*	21	I/O	**Data Valid:** IEEE GPIB handshake control line. When an input, this pin is a TTL compatible Schmitt-trigger. When DAV* is an output, it can sink 48 mA.
$\overline{DIO1}$-$\overline{DIO8}$	25, 23, 10, 9, 8, 7, 6, 5	I/O	**Data Input/Output:** Processor GPIB bus data lines; used to carry message and data bytes in a bit-parallel byte-serial from controlled by the three handshake signals. These lines are TTL compatible.
DIO1* DIO8*	22, 19, 18, 17, 16, 15, 13, 12	I/O	**Data Input/Output:** IEEE GPIB bus data lines. They are TTL compatible Schmitt-triggers when used for input and can sink 48 mA when used for output.

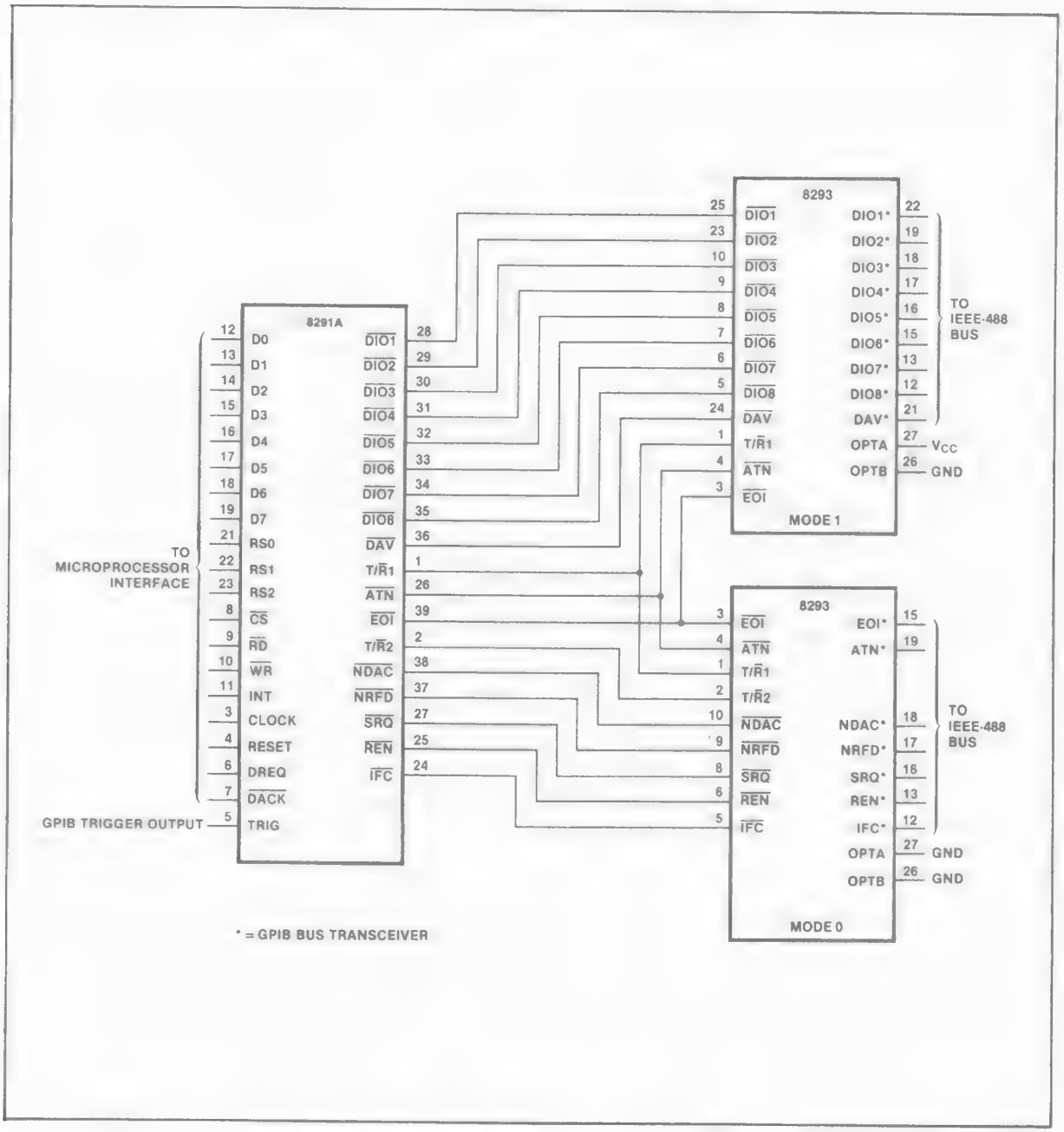

Figure 9. 8291A and 8293 System Configuration

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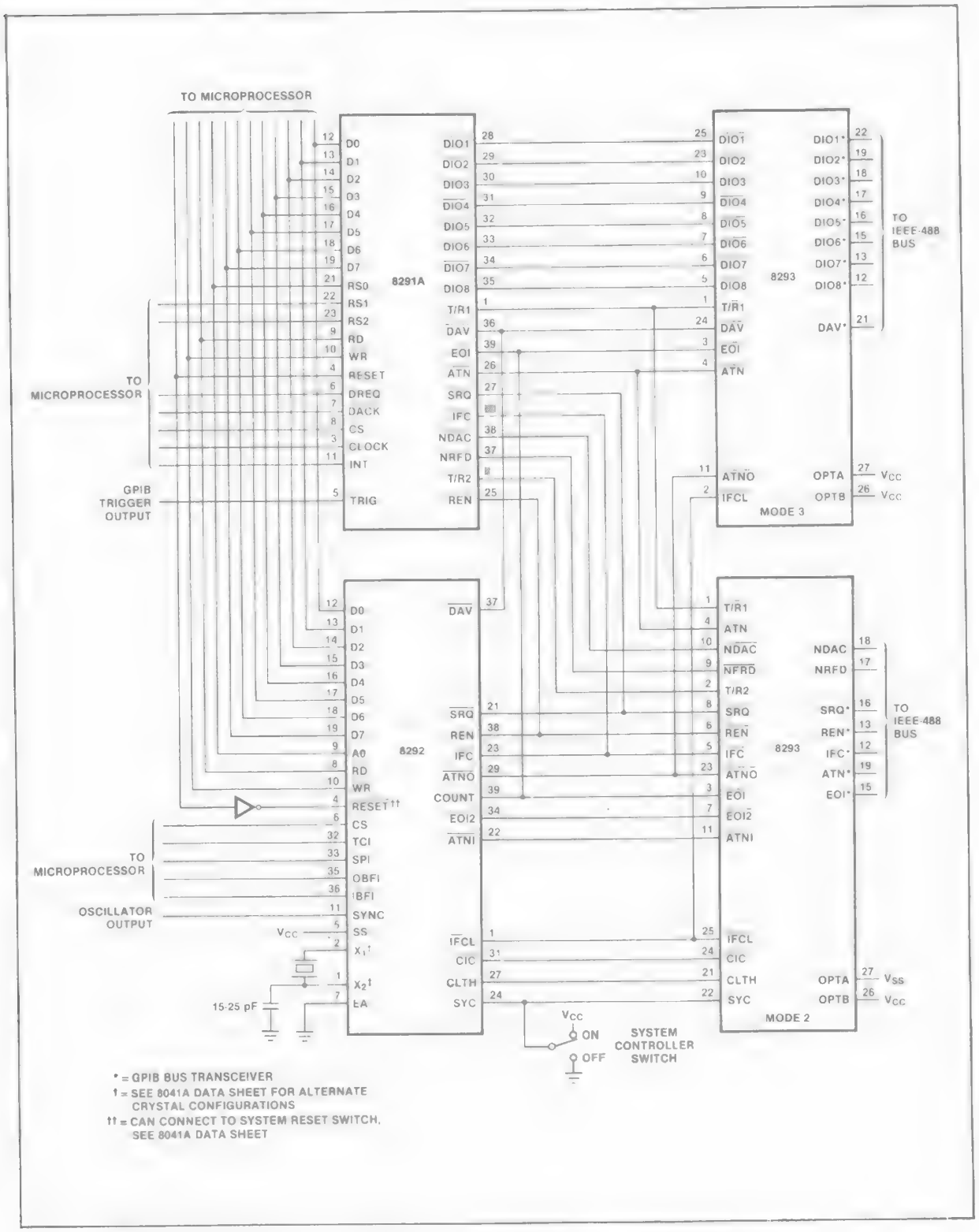


Figure 10. 8291A, 8292, and 8293 System Configuration

AFN-00825C

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias.....0°C to 70°C
Storage Temperature.....−65°C to +150°C
Voltage on any Pin with
Respect to Ground.....−1.0V to +7V
Power Dissipation.....1 Watt

*NOTICE:
1. *Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*
2. *All devices are guaranteed to operate within the minimum and maximum parameter limits specified below. Typical parameters however are not tested and are not guaranteed. Established statistically, they indicate the performance level expected in a typical device at room temperature (T_A = 25°C) and V_{CC} = 5V.*

D.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5.0V ±10%, GND = 0V)

Symbol	Parameter		Limits Min.	Typ.	Max.	Units	Test Conditions
V_{IL1}	Input Low Voltage (GPIB Bus Pins)				0.8	V	
V_{IL2}	Input Low Voltage (Option Pins)		−0.1		0.1	V	
V_{IL3}[1]	Input Low Voltage (All Others)				0.8	V	
V_{IH1}	Input High Voltage (GPIB Bus Pins)		2.0		V_{CC}	V	
V_{IH2}	Input High Voltage (Option Pins)		4.5		V_{CC}	V	
V_{IH3}	Input High voltage (All Others)		2.0		V_{CC}	V	
V_{IH4}	Receiver Input Hysteresis		400			mV	
V_{OL1}	Output Low Voltage (GPIB Bus Pins)				0.5	V	I_{OL} = 48 mA
V_{OL2}	Output Low Voltage (All Others)				0.5	V	I_{OL} = 16 mA
V_{OH1}	Output High Voltage (GPIB Bus Pins)		2.4			V	I_{OH} = −5.2 mA
V_{OH2}	Output High Voltage (All Others)		2.4			V	I_{OH} = −800 μA
V_{IT}	Receiver Input Threshold	High to Low	0.8			V	
		Low to High			2.0		
I_{LC}	Input Load Current (GPIB Pins)		See Bus Load Line Diagram				V_{CC} = 5.0V ± 5%
I_{IL}	Input Leakage Current (All Others)				10	μA	0.45 ≤ V_{IN} ≤ V_{CC}
I_{PD}	Bus Power Down Leakage Current				40	μA	0.45V ≤ V_{BUS} ≤ 2.7V
I_{CC}	Power Supply Current			110	175	mA	

NOTES:
1. V_{IL3} = 1.1V max on pins 21 and 22 in Mode 2 for the 8293-10.

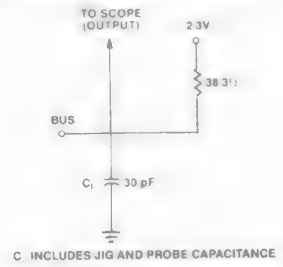
CAPACITANCE

Symbol	Parameter	Min.	Typ.	Max.	Units	Test Conditions
C_{IO1}	I/O Capacitance (GPIB Side)		50	80	pF	V_{IN} = V_{CC}
C_{IO2}	I/O Capacitance (System Side)		35	50	pF	V_{IN} = V_{CC}
C_{ITR}	Input Capacitance (T/R1, T/R2)		7	10	pF	V_{IN} = V_{CC}

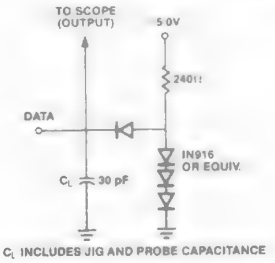
A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = 5.0V ±10%, GND = 0V)

Symbol	Parameter	Max.	Units
t_{P1}	Transmitter Propagation Delay (All Lines)	30	ns
t_{P2}	Receiver Propagation Delay (EOI, ATN and Handshake Lines)	50	ns
t_{P3}	Receiver Propagation Delay (All Other Lines)	50	ns
t_{PHZ1}	Transmitter Disable Delay (High to 3-State)	40	ns
t_{PZH1}	Transmitter Enable Delay (3-state to High)	40	ns
t_{PLZ1}	Transmitter Disable Delay (Low to 3-State)	40	ns
t_{PZL1}	Transmitter Enable Delay (3-State to Low)	40	ns
t_{PHZ2}	Receiver Disable Delay (High to 3-State)	40	ns
t_{PZH2}	Receiver Enable Delay (3-State to High)	40	ns
t_{PLZ2}	Receiver Disable Delay (Low to 3-State)	40	ns
t_{PZL2}	Receiver Enable Delay (3-State to Low)	40	ns
t_{MS}	Mode Switch Delay	10	μs

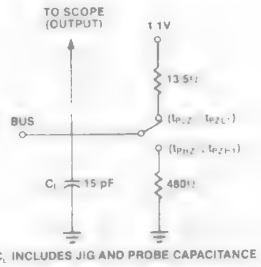
TYPICAL OUTPUT LOADING CIRCUITS



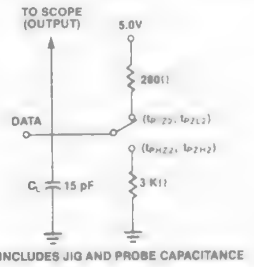
Data Input to Bus Output (Driver)



Bus Input to Data Output (Receiver)

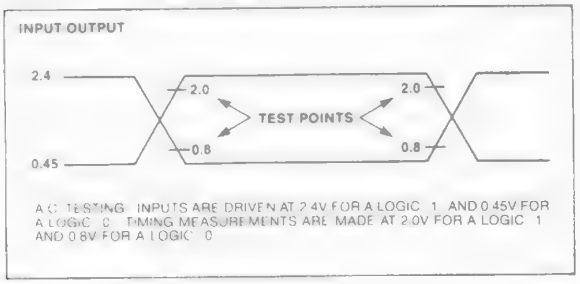


Send/Receive Input to Bus Output (Driver)

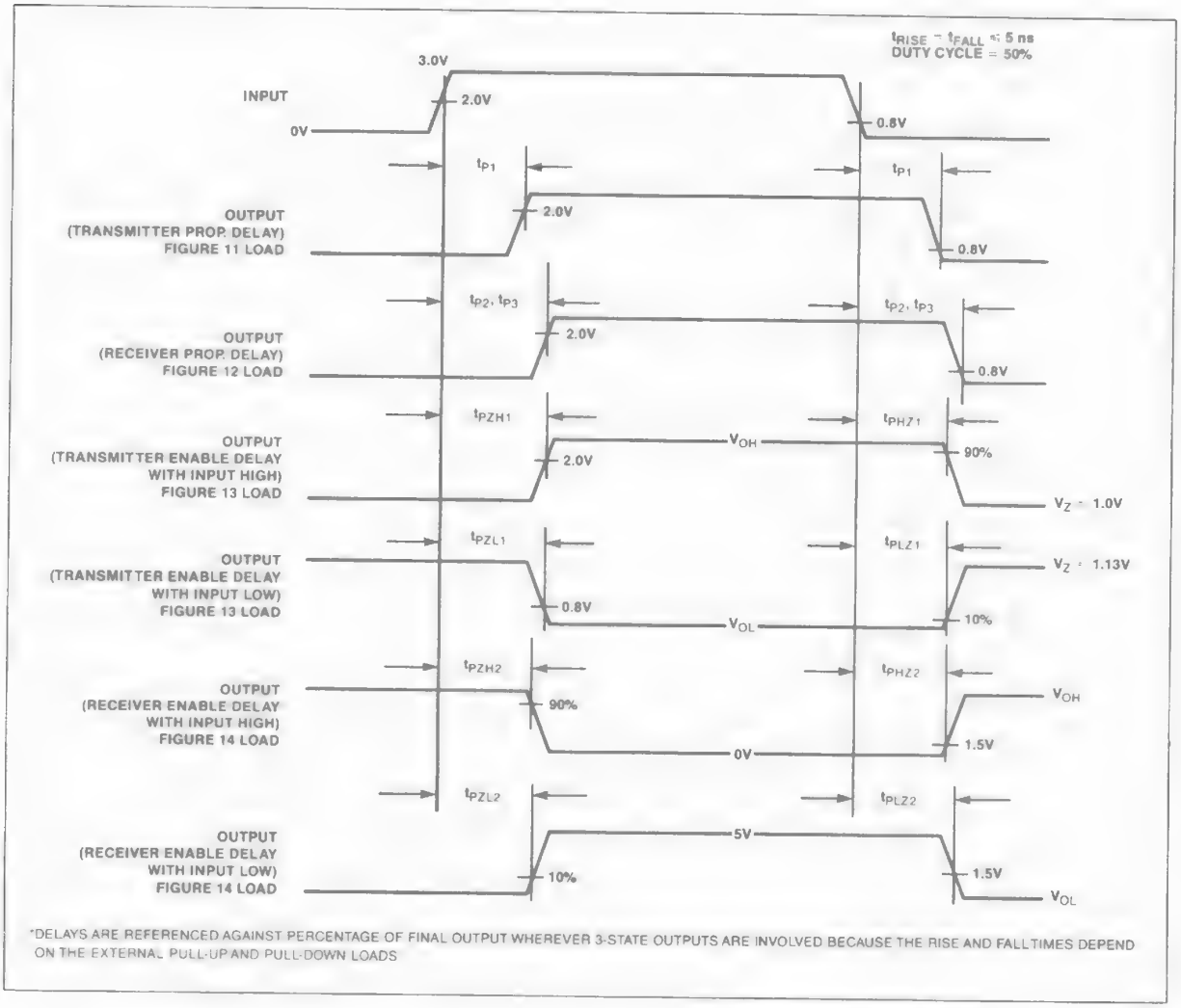


Send/Receive Input to Data Output (Receiver)

A.C. TESTING INPUT, OUTPUT WAVEFORM

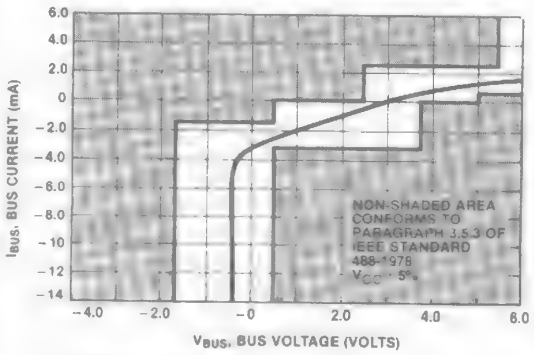


WAVEFORMS

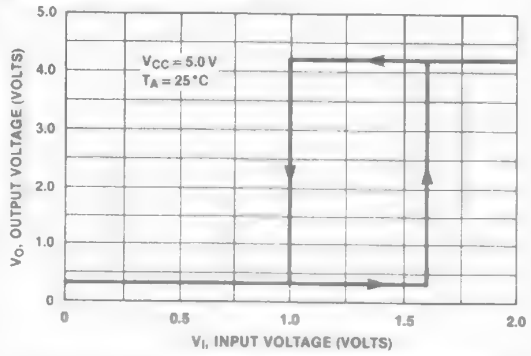


*DELAYS ARE REFERENCED AGAINST PERCENTAGE OF FINAL OUTPUT WHEREVER 3-STATE OUTPUTS ARE INVOLVED BECAUSE THE RISE AND FALL TIMES DEPEND ON THE EXTERNAL PULL-UP AND PULL-DOWN LOADS

BUS LOAD LINE



TYPICAL RECEIVER HYSTERESIS CHARACTERISTICS



AFN-00825C

8294A
DATA ENCRYPTION UNIT

- Certified by National Bureau of Standards
- 400 Byte/Sec Data Conversion Rate
- 64-Bit Data Encryption Using 56-Bit Key
- DMA Interface
- 3 Interrupt Outputs to Aid in Loading and Unloading Data
- 7-Bit User Output Port
- Single 5V ± 10% Power Supply
- Fully Compatible with iAPX-86,88, MCS-85™, MCS-80™, MCS-51™, and MCS-48™ Processors
- Implements Federal Information Processing Data Encryption Standard
- Encrypt and Decrypt Modes Available

The Intel® 8294A Data Encryption Unit (DEU) is a microprocessor peripheral device designed to encrypt and decrypt 64-bit blocks of data using the algorithm specified in the Federal Information Processing Data Encryption Standard. The DEU operates on 64-bit text words using a 56-bit user-specified key to produce 64-bit cipher words. The operation is reversible: if the cipher word is operated upon, the original text word is produced. The algorithm itself is permanently contained in the 8294A; however, the 56-bit key is user-defined and may be changed at any time.

The 56-bit key and 64-bit message data are transferred to and from the 8294A in 8-bit bytes by way of the system data bus. A DMA interface and three interrupt outputs are available to minimize software overhead associated with data transfer. Also, by using the DMA interface two or more DEUs may be operated in parallel to achieve effective system conversion rates which are virtually any multiple of 400 bytes/second. The 8294A also has a 7-bit TTL compatible output port for user-specified functions.

Because the 8294A implements the NBS encryption algorithm it can be used in a variety of Electronic Funds Transfer applications as well as other electronic banking and data handling applications where data must be encrypted.

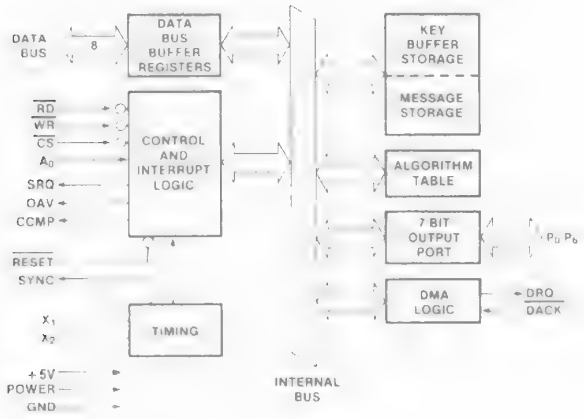


Figure 1. Block Diagram

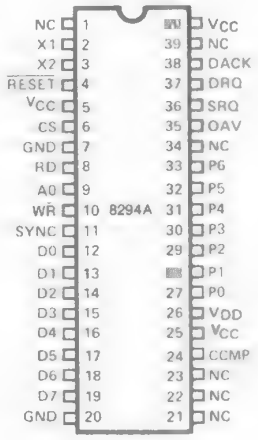


Figure 2. Pin Configuration

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ORDER NUMBER: 210465-002

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
NC	1		**No Connection.**
X1 X2	2 3	I	**Crystal:** Inputs for crystal, L-C or external timing signal to determine internal oscillator frequency.
$\overline{RESET}$	4	I	**Reset:** A low signal to this pin resets the 8294A.
V_{CC}	5		**Power:** Tied high.
$\overline{CS}$	6	I	**Chip Select:** A low signal to this pin enables reading and writing to the 8294A.
GND	7		**Ground:** This pin must be tied to ground.
$\overline{RD}$	8	I	**Read:** An active low read strobe at this pin enables the CPU to read data and status from the internal DEU registers.
A_0	9	I	**Address:** Address input used by the CPU to select DEU registers during read and write operations.
$\overline{WR}$	10	I	**Write:** An active low write strobe at this pin enables the CPU to send data and commands to the DEU.
SYNC	11	O	**Sync:** High frequency (Clock ÷ 15) output. Can be used as a strobe for external circuitry.
D_0 D_1 D_2 D_3 D_4 D_5 D_6 D_7	12 13 14 15 16 17 18 19	I/O	**Data Bus:** Three-state, bi-directional data bus lines used to transfer data between the CPU and the 8294A.
GND	20		**Ground:** This pin must be tied to ground.
V_{CC}	40		**Power:** +5 volt power input: +5V ± 10%.

Symbol	Pin No.	Type	Name and Function
NC	39		**No Connection**
$\overline{DACK}$	38	I	**DMA Acknowledge:** Input signal from the 8257 DMA Controller acknowledging that the requested DMA cycle has been granted.
DRQ	37	O	**DMA Request:** Output signal to the 8257 DMA Controller requesting a DMA cycle.
SRQ	36	O	**Service Request:** Interrupt to the CPU indicating that the 8294A is awaiting data or commands at the input buffer. SRQ=1 implies IBF=0.
OAV	35	O	**Output Available:** Interrupt to the CPU indicating that the 8294A has data or status available in its output buffer. OAV=1 implies OBF=1.
NC	34		**No Connection.**
P6 P5 P4 P3 P2 P1 P0	33 32 31 30 29 28 27	O	**Output Port:** User output port lines. Output lines available to the user via a CPU command which can assert selected port lines. These lines have nothing to do with the encryption function. At power-on, each line is in a 1 state
V_{DD}	26		**Power:** +5V power input. (+5V +10%) Low power standby pin.
V_{CC}	25		**Power:** Tied high.
CCMP	24	O	**Conversion Complete:** Interrupt to the CPU indicating that the encryption/decryption of an 8-byte block is complete.
NC	23		**No Connection.**
NC	22		**No Connection.**
NC	21		**No Connection.**

FUNCTIONAL DESCRIPTION

OPERATION

The data conversion sequence is as follows:

1. A Set Mode command is given, enabling the desired interrupt outputs.
2. An Enter New Key command is issued, followed by 8 data inputs which are retained by the DEU for encryption/decryption. Each byte must have odd parity.
3. An Encrypt Data or Decrypt Data command sets the DEU in the desired mode.

After this, data conversions are made by writing 8 data bytes and then reading back 8 converted data bytes. Any of the above commands may be issued between data conversions to change the basic operation of the DEU; e.g., a Decrypt Data command could be issued to change the DEU from encrypt mode to decrypt mode without changing either the key or the interrupt outputs enabled.

INTERNAL DEU REGISTERS

Four internal registers are addressable by the master processor: 2 for input, and 2 for output. The following table describes how these registers are accessed.

$\overline{RD}$	$\overline{WR}$	$\overline{CS}$	A_0	Register
1	0	0	0	Data input buffer
0	1	0	0	Data output buffer
1	0	0	1	Command input buffer
0	1	0	1	Status output buffer
X	X	1	X	Don't care

The functions of each of these registers are described below.

Data Input Buffer — Data written to this register is interpreted in one of three ways, depending on the preceding command sequence.

1. Part of a key.
2. Data to be encrypted or decrypted.
3. A DMA block count.

Data Output Buffer — Data read from this register is the output of the encryption/decryption operation.

Command Input Buffer — Commands to the DEU are written into this register. (See command summary below.)

Status Output Buffer — DEU status is available in this register at all times. It is used by the processor for poll-driven command and data transfer operations.

STATUS BIT:	7	6	5	4	3	2	1	0
FUNCTION:	X	X	X	KPE	CF	DEC	IBF	OBF

OBF Output Buffer Full; OBF = 1 indicates that output from the encryption/decryption function is available in the Data Output Buffer. It is reset when the data is read.

IBF Input Buffer Full; A write to the Data Input Buffer or to the Command Input Buffer sets IBF = 1. The DEU resets this flag when it has accepted the input byte. Nothing should be written when IBF = 1.

DEC Decrypt; indicates whether the DEU is in an encrypt or a decrypt mode. DEC = 1 implies the decrypt mode. DEC = 0 implies the encrypt mode.

After 8294A has accepted a 'Decrypt Data' or 'Encrypt Data' command, 11 cycles are required to update the DEC bit.

CF Completion Flag; This flag may be used to indicate any or all of three events in the data transfer protocol.

1. It may be used in lieu of a counter in the processor routine to flag the end of an 8-byte transfer.
2. It must be used to indicate the validity of the KPE flag.
3. It may be used in lieu of the CCMP interrupt to indicate the completion of a DMA operation.

KPE Key Parity Error; After a new key has been entered, the DEU uses this flag in conjunction with the CF flag to indicate correct or incorrect parity.

COMMAND SUMMARY

1 — Enter New Key

OP CODE:

0	1	0	0	0	0	0	0

MSB LSB

This command is followed by 8 data byte inputs which are retained in the key buffer (RAM) to be used in encrypting and decrypting data. These data bytes must have odd parity represented by the LSB.

2 — Encrypt Data

OP CODE:

0	0	1	1	0	0	0	0

MSB LSB

This command puts the 8294A into the encrypt mode.

3 — Decrypt Data

OP CODE

0	0	1	0	0	0	0	0

MSB LSB

This command puts the 8294A into the decrypt mode.

4 — Set Mode

OP CODE:

0	0	0	0	A	B	C	D

MSB LSB

where:

A is the OAV (Output Available) interrupt enable
B is the SRQ (Service Request) interrupt enable
C is the DMA (Direct Memory Access) transfer enable
D is the CCMP (Conversion Complete) interrupt enable

This command determines which interrupt outputs will be enabled. A "1" in bits A, B, or D will enable the OAV, SRQ, or CCMP interrupts respectively. A "1" in bit C will allow DMA transfers. When bit C is set the OAV and SRQ interrupts should also be enabled (bits A,B = 1). Following the command in which bit C, the DMA bit, is set, the 8294 will expect one data byte to specify the number of 8-byte blocks to be converted using DMA

5 — Write to Output Port

OP CODE	1	P_6	P_5	P_4	P_3	P_2	P_1	P_0
	MSB							LSB

This command causes the 7 least significant bits of the command byte to be latched as output data on the 8294 output port. The initial output data is 1111111. Use of this port is independent of the encryption/decryption function.

PROCESSOR/DEU INTERFACE PROTOCOL

ENTERING A NEW KEY

The timing sequence for entering a new key is shown in Figure 3. A flowchart showing the CPU software to accommodate this sequence is given in Figure 4.

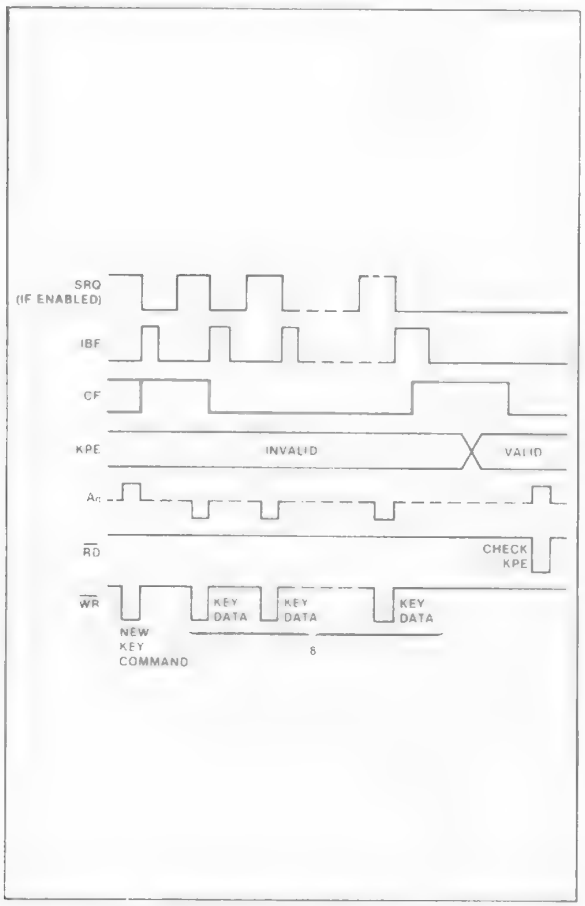

Figure 3. Entering a New Key

After the Enter New Key command is issued, 8 data bytes representing the new key are written to the data input buffer (most significant byte first). After the eighth byte is entered into the DEU, CF goes true (CF=1). The CF bit goes false again when KPE is valid. The CPU can then check the KPE flag. If KPE=1, a parity error has been detected and the DEU has not accepted the key. Each byte is checked for odd parity, where the parity bit is the LSB of each byte.

Since CF=1 only for a short period of time after the last byte is accepted, the CPU which polls the CF flag might miss detecting CF=1 momentarily. Thus, a counter should be used, as in Figure 4, to flag the end of the new key entry. Then CF is used to indicate a valid KPE flag.

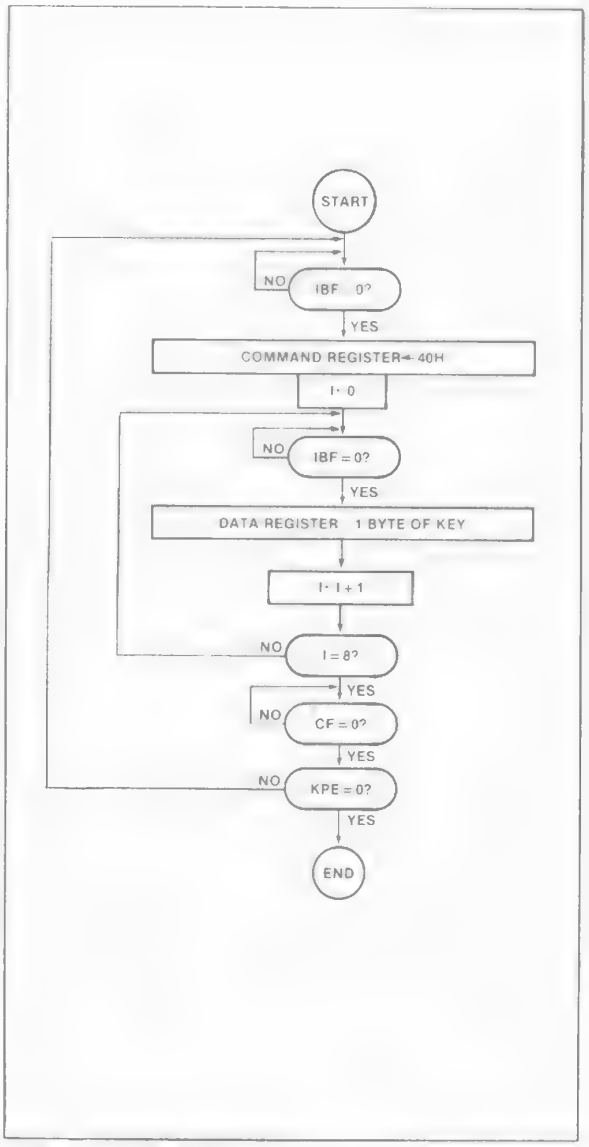

Figure 4. Flowchart for Entering a New Key

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ENCRYPTING OR DECRYPTING DATA

Figure 5 shows the timing sequence for encrypting or decrypting data. The CPU writes 8 data bytes to the DEU's data input buffer for encryption/decryption. CF then goes true (CF = 1) to indicate that the DEU has accepted the 8-byte block. Thus, the CPU may test for IBF = 0 and CF = 1 to terminate the input mode, or it may use a software counter. When the encryption/-decryption is complete, the CCMP and OAV interrupts are asserted and the OBF flag is set true (OBF = 1). OAV and OBF are set false again after each of the converted data bytes is read back by the CPU. The CCMP interrupt is set false, and remains false, after the first read. After 8 bytes have been read back by the CPU, CF goes false (CF = 0). Thus, the CPU may test for CF = 0 to terminate the read mode. Also, the CCMP interrupt may be used to initiate a service routine which performs the next series of 8 data reads and 8 data writes.

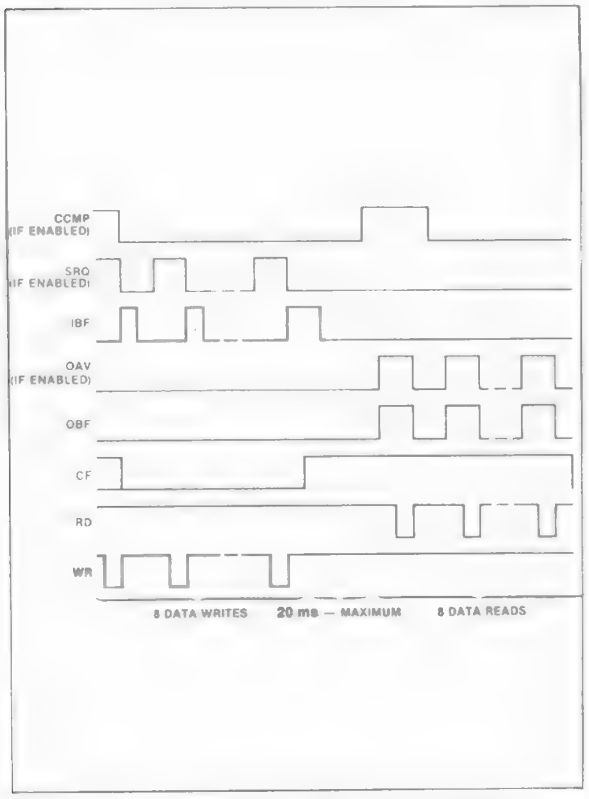


Figure 5. Encrypting/Decrypting Data

Figure 6 offers two flowcharts outlining the alternative means of implementing the data conversion protocol. Either the CF flag or a software counter may be used to end the read and write modes.

SRQ = 1 implies IBF = 0, OAV = 1 implies OBF = 1. This allows interrupt routines to do data transfers without checking status first. However, the OAV service routine must detect and flag the end of a data conversion.

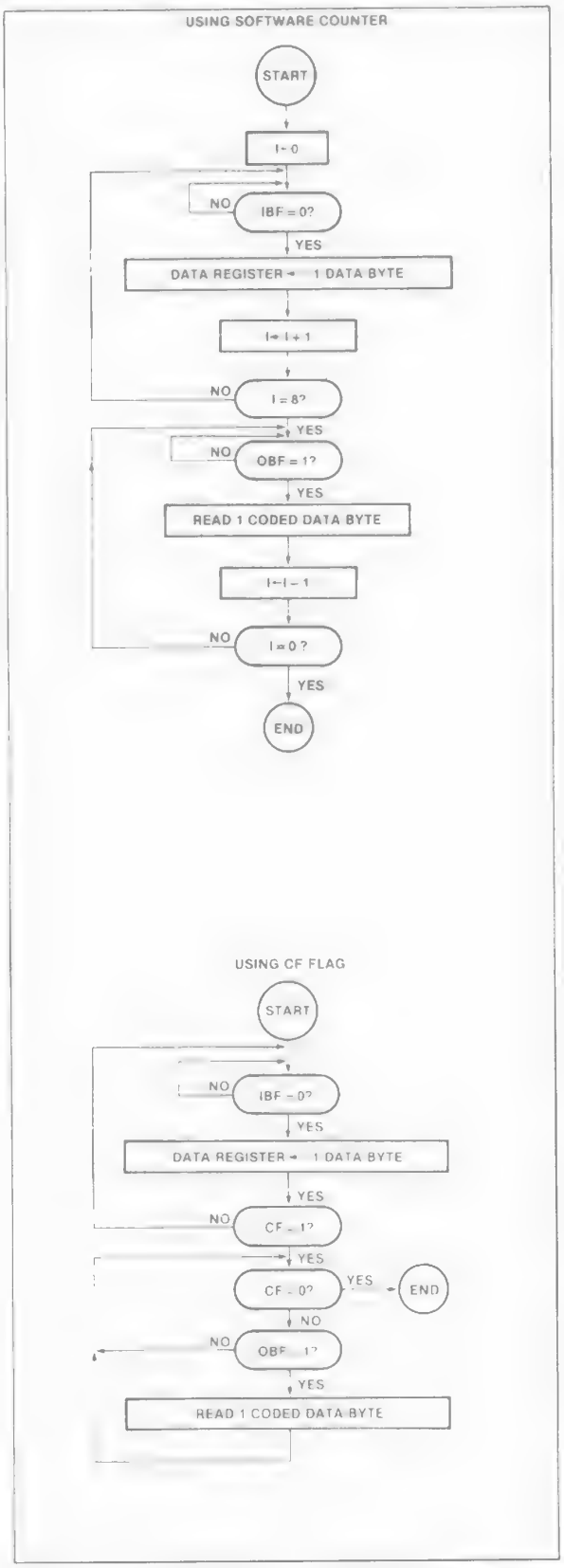


Figure 6. Data Conversion Flowcharts

USING DMA

The timing sequence for data conversions using DMA is shown in Figure 7. This sequence can be better understood when considered in conjunction with the hardware DMA interface in Figure 8. Note that the use of the DMA feature requires 3 external AND gates and 2 DMA channels (one for input, one for output). Since the DEU has only one DMA request pin, the SRQ and OAV outputs are used in conjunction with two of the AND gates to create separate DMA request outputs for the 2 DMA channels. The third AND gate combines the two active-low $\overline{DACK}$ inputs.

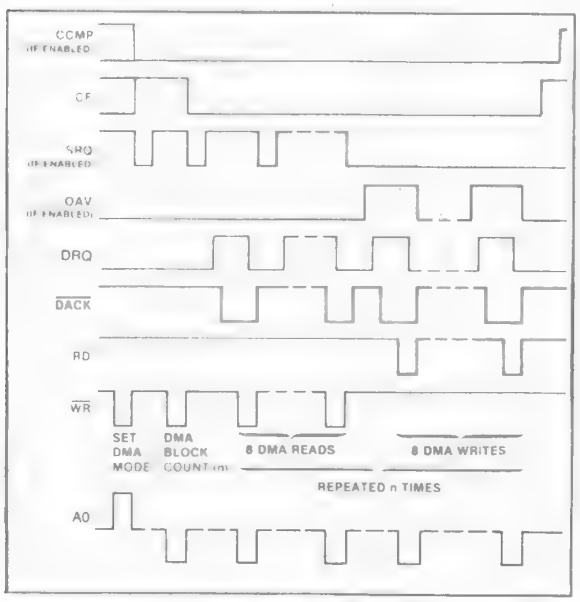


Figure 7. DMA Sequence

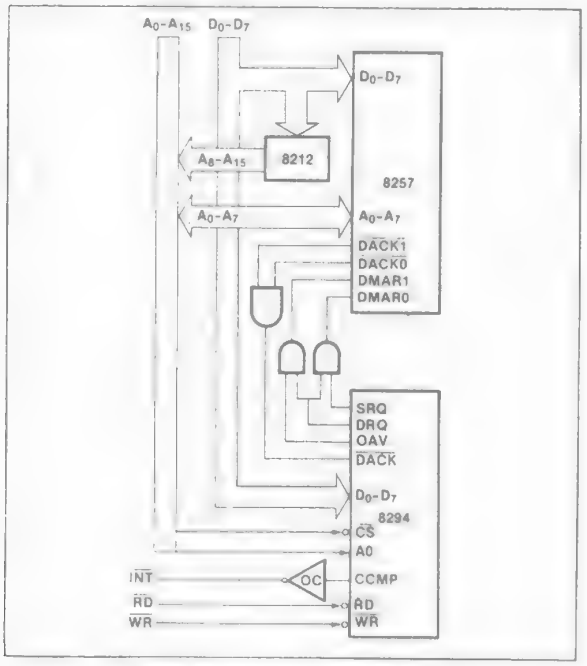


Figure 8. DMA Interface

To initiate a DMA transfer, the CPU must first initialize the two DMA channels as shown in the flowchart in Figure 9. It must then issue a Set Mode command to the DEU enabling the OAV, SRQ, and DMA outputs. The CCMP interrupt may be enabled or disabled, depending on whether that output is desired. Following the Set Mode command, there must be a data byte giving the number of 8-byte blocks of data (n<256) to be converted. The DEU then generates the required number of DMA requests to the 2 DMA channels with no further CPU intervention. When the requested number of blocks has been converted, the DEU will set CF and assert the CCMP interrupt (if enabled). CCMP then goes false again with the next write to the DEU (command or data). Upon completion of the conversion, the DMA mode is disabled and the DEU returns to the encrypt/decrypt mode. The enabled interrupt outputs, however, will remain enabled until another Set Mode command is issued.

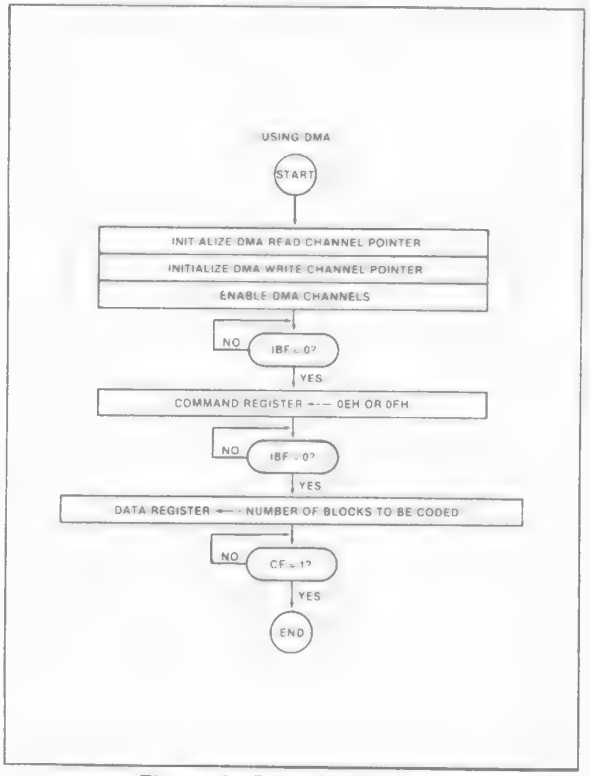


Figure 9. DMA Flowchart

SINGLE BYTE COMMANDS

Figure 10 shows the timing and protocol for single byte commands. Note that any of the commands is effective as a pacify command in that they may be entered at any time, except during a DMA conversion. The DEU is thus set to a known state. However, if a command is issued out of sequence, an additional protocol is required (Figure 11). The CPU must wait until the command is accepted (IBF = 0). A data read must then be issued to clear anything the preceding command sequence may have left in the Data Output Buffer.

CPU/DEU INTERFACES

Figures 12 through 15 illustrate four interface configurations used in the CPU/DEU data transfers. In all cases SRQ will be true (if enabled) and IBF will be false when the DEU is ready to accept data or commands

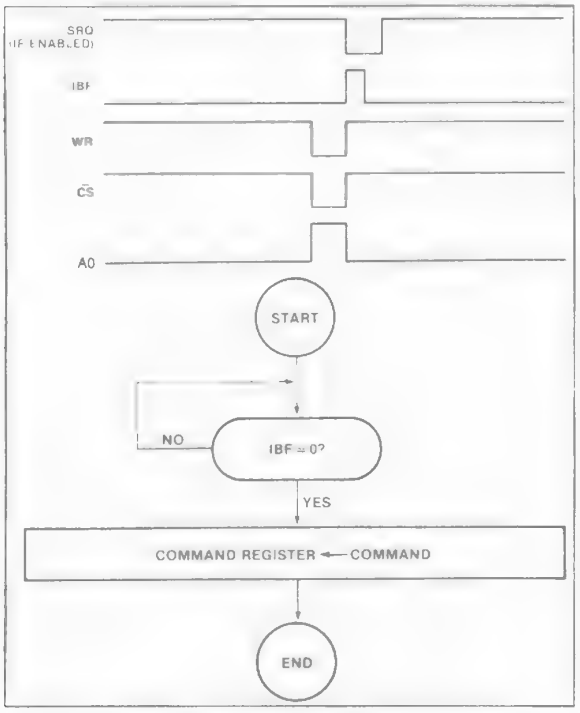


Figure 10. Single Byte Commands

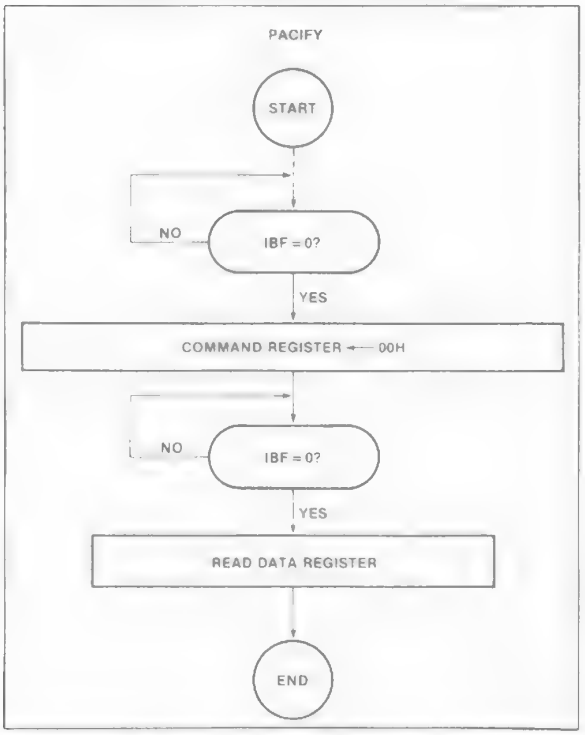


Figure 11. Pacify Protocol

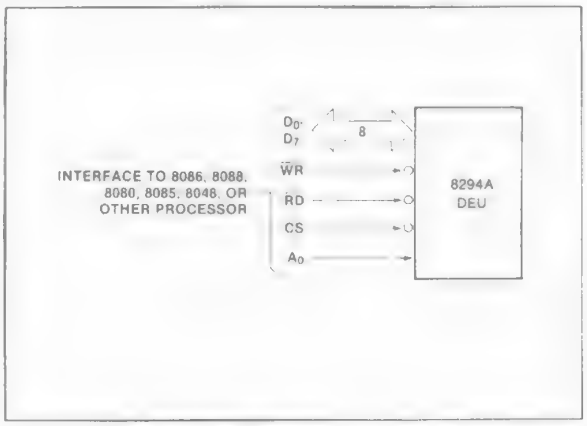


Figure 12. Polling Interface

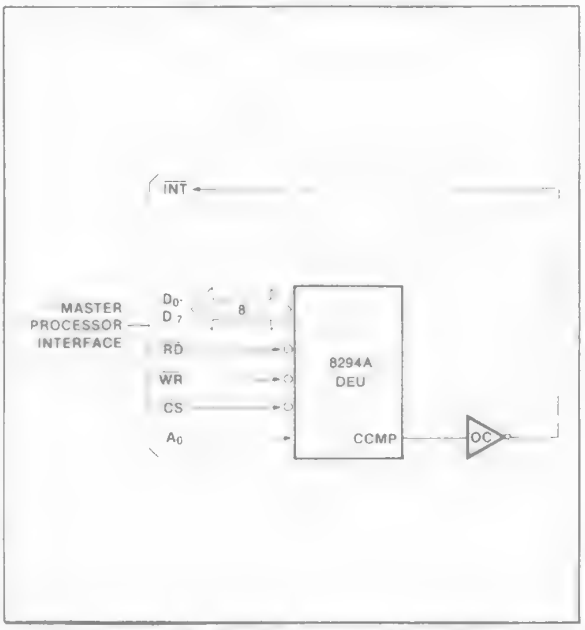


Figure 13. Single Interrupt Interface

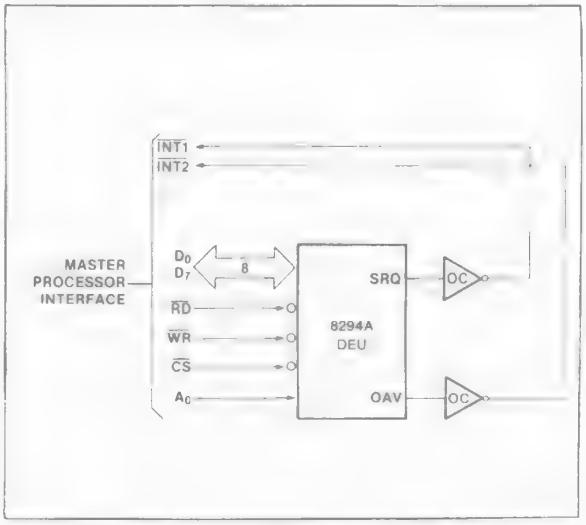


Figure 14. Dual Interrupt Interface

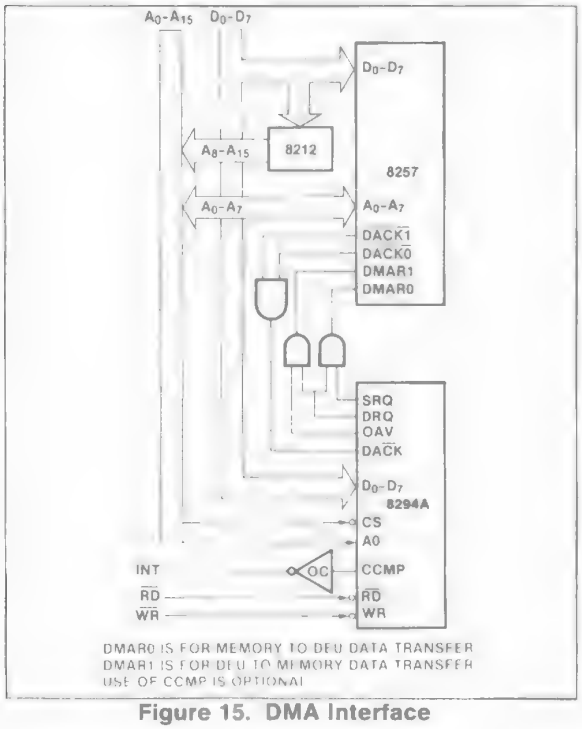


Figure 15. DMA Interface

OSCILLATOR AND TIMING CIRCUITS

The 8294A's internal timing generation is controlled by a self-contained oscillator and timing circuit. A choice of crystal, L-C or external clock can be used to derive the basic oscillator frequency.

The resident timing circuit consists of an oscillator, a state counter and a cycle counter as illustrated in Figure 16.

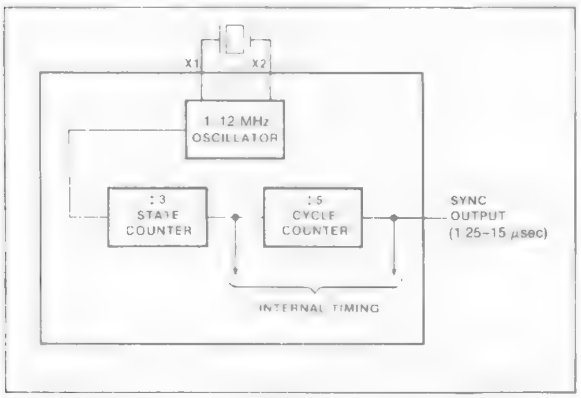


Figure 16. Oscillator Configuration

OSCILLATOR

The on-board oscillator is a series resonant circuit with a frequency range of 1 to 12 MHz. Pins X1 and X2 are input and output (respectively) of a high gain amplifier stage. A crystal or inductor and capacitator connected between X1 and X2 provide the feedback and proper phase shift for oscillation. Recommended connections for crystal or L-C are shown in Figure 17.

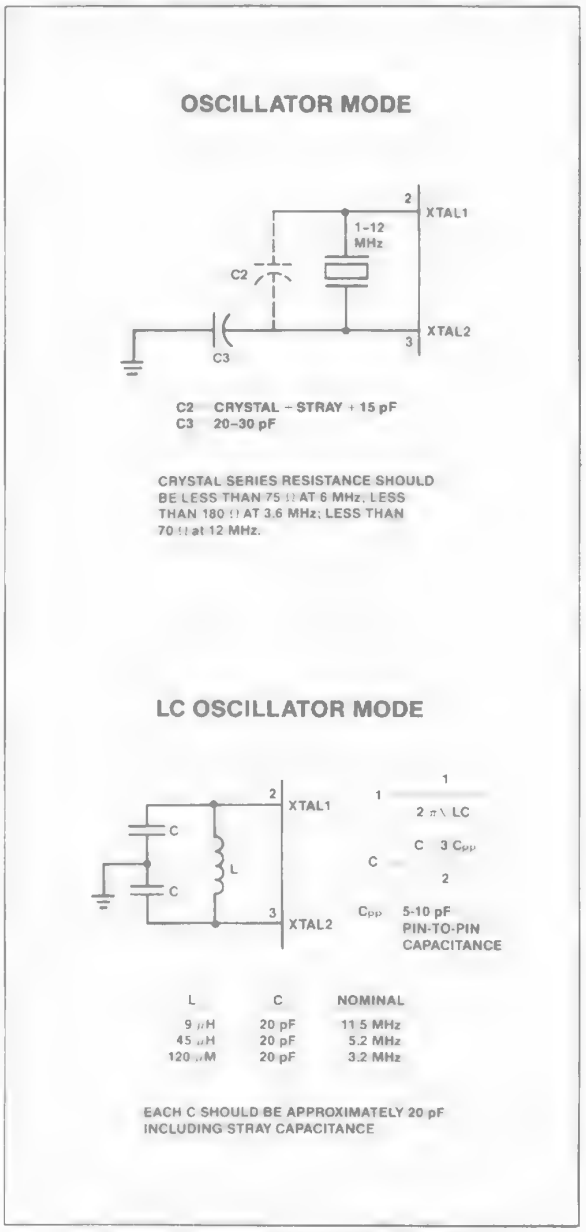


Figure 17. Recommended Crystal and L-C Connections

A recommended range of inductance and capacitance combinations is given below:

L = 120μH corresponds to 3 MHz
L = 45μH corresponds to 5 MHz
L = 9μH corresponds to 11 MHz

An external clock signal can also be used as a frequency reference to the 8294A; however, the levels are *not* TTL compatible. The signal must be in the 1 MHz–12 MHz frequency range and must be connected to pins X1 and X2 by buffers with a suitable pull-up resistor to guarantee that a logic "1" is above 3.0 volts. The recommended connection is shown in Figure 18.

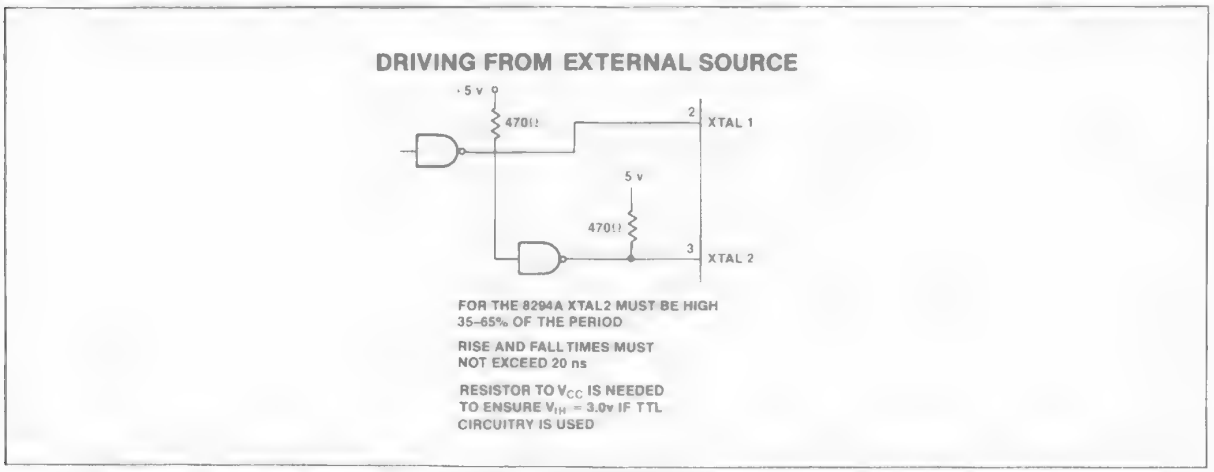


Figure 18. Recommended Connection for External Clock Signal

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to +150°C
Voltage on Any Pin With
Respect to Ground ..... −0.5V to +7V
Power Dissipation ..... 1.5 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. AND OPERATING CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = +5V ± 10%, V_{SS} = 0V)

Symbol	Parameter	Limits Min.	Limits Typ.	Limits Max.	Unit	Test Conditions
V_{IL}	Input Low Voltage (All Except X_1, X_2, $\overline{RESET}$)	−0.5		0.8	V	
V_{IL1}	Input Low Voltage (X_1, X_2, $\overline{RESET}$)	−0.5		0.6	V	
V_{IH}	Input High Voltage (All Except X_1, X_2, $\overline{RESET}$)	2.2		V_{CC}	V	
V_{IH1}	Input High Voltage (X_1, X_2, $\overline{RESET}$)	3.0		V_{CC}	V	
V_{OL}	Output Low Voltage (D_0–D_7)			0.45	V	I_{OL} = 2.0 mA
V_{OL1}	Output Low Voltage (All Other Outputs)			0.45	V	I_{OL} = 1.6 mA
V_{OH}	Output High Voltage (D_0–D_7)	2.4			V	I_{OH} = −400 μA
V_{OH1}	Output High Voltage (All Other Outputs)	2.4			V	I_{OH} = −50 μA
I_{IL}	Input Leakage Current ($\overline{RD}$, $\overline{WR}$, $\overline{CS}$, $\overline{A_0}$)			±10	μA	$V_{SS} \leq V_{IN} \leq V_{CC}$
I_{OFL}	Output Leakage Current (D_0–D_7, High Z State)			±10	μA	V_{SS} + 0.45 ≤ V_{OUT} ≤ V_{CC}
I_{DD}	V_{DD} Supply Current		5	15	mA	
$I_{DD} + I_{CC}$	Total Supply Current		60	125	mA	
I_{LI}	Low Input Load Current (Pins 24, 27–38)			0.3	mA	V_{IL} = 0.8 V
I_{LI1}	Low Input Load Current ($\overline{RESET}$)			0.2	mA	V_{IL} = 0.8 V
I_{IH}	Input High Leakage Current (Pins 24, 27-38)			100	μA	V_{IN} = V_{CC}
C_{IN}	Input Capacitance			10	pF	
$C_{I/O}$	I/O Capacitance			20	pF	

A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = V_{DD} = +5V ± 10%, V_{SS} = 0V)

DBB READ

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AR}	$\overline{CS}$, A_0 Setup to $\overline{RD}$ ↓	0		ns	
t_{RA}	$\overline{CS}$, A_0 Hold After $\overline{RD}$ ↑	0		ns	
t_{RR}	$\overline{RD}$ Pulse Width	160		ns	
t_{AD}	$\overline{CS}$, A_0 to Data Out Delay		130	ns	C_L = 100 pF
t_{RD}	$\overline{RD}$ ↓ to Data Out Delay		130	ns	C_L = 100 pF
t_{DF}	$\overline{RD}$ ↑ to Data Float Delay		85	ns	
t_{CY}	Cycle Time	1.25	15	μs	1–12 MHz Crystal

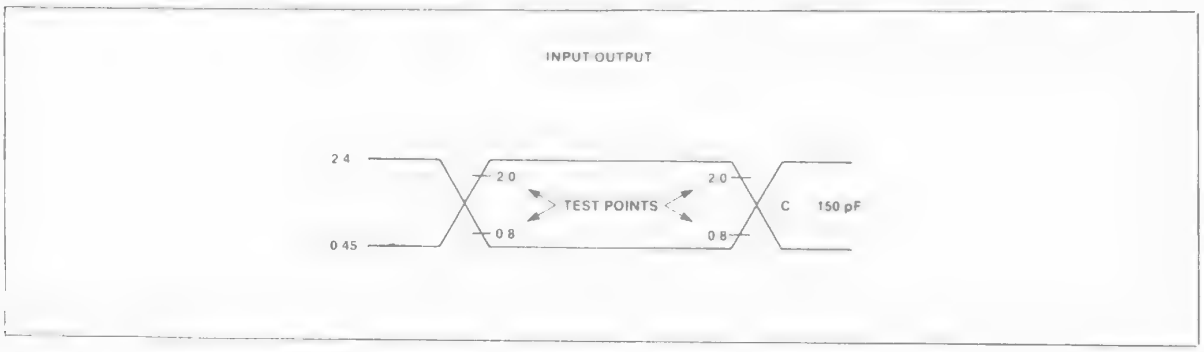
DBB WRITE

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AW}	$\overline{CS}$, A_0 Setup to $\overline{WR}$ ↓	0		ns	
t_{WA}	$\overline{CS}$, A_0 Hold After $\overline{WR}$ ↑	0		ns	
t_{WW}	$\overline{WR}$ Pulse Width	160		ns	
t_{DW}	Data Setup to $\overline{WR}$ ↑	130		ns	
t_{WD}	Data Hold to $\overline{WR}$ ↑	0		ns	

DMA AND INTERRUPT TIMING

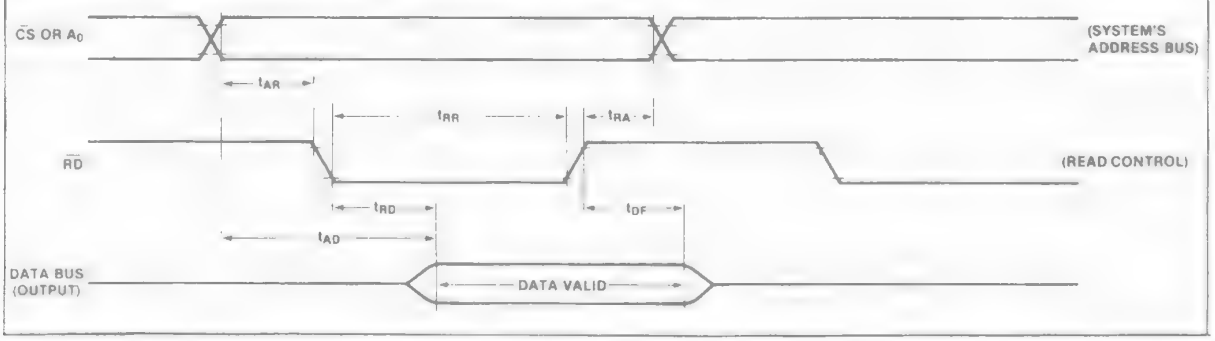
Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{ACC}	$\overline{DACK}$ Setup to Control	0		ns	
t_{CAC}	$\overline{DACK}$ Hold After Control	0		ns	
t_{ACD}	$\overline{DACK}$ to Data Valid		130	ns	C_L = 100 pF
t_{CRQ}	Control L.E. to DRQ T.E.		100	ns	
t_{CI}	Control T.E. to Interrupt T.E.		400	ns	

A.C. TESTING INPUT, OUTPUT WAVEFORM

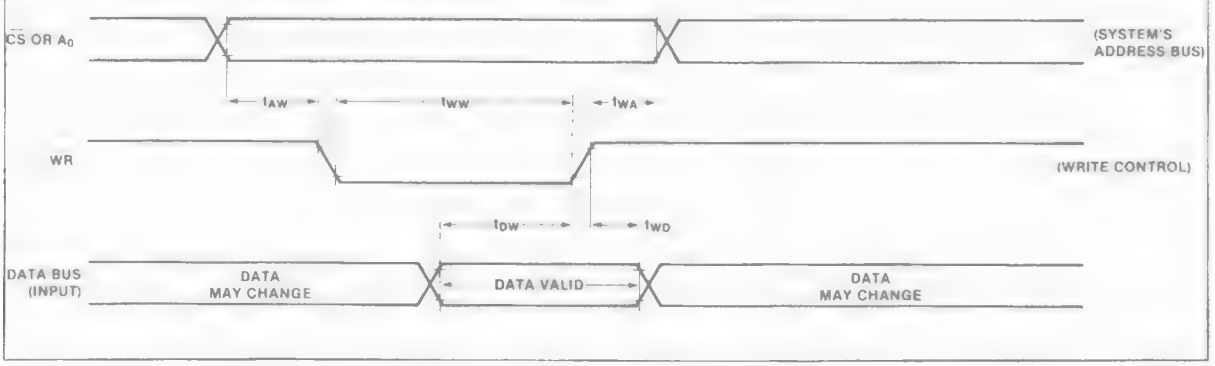


WAVEFORMS

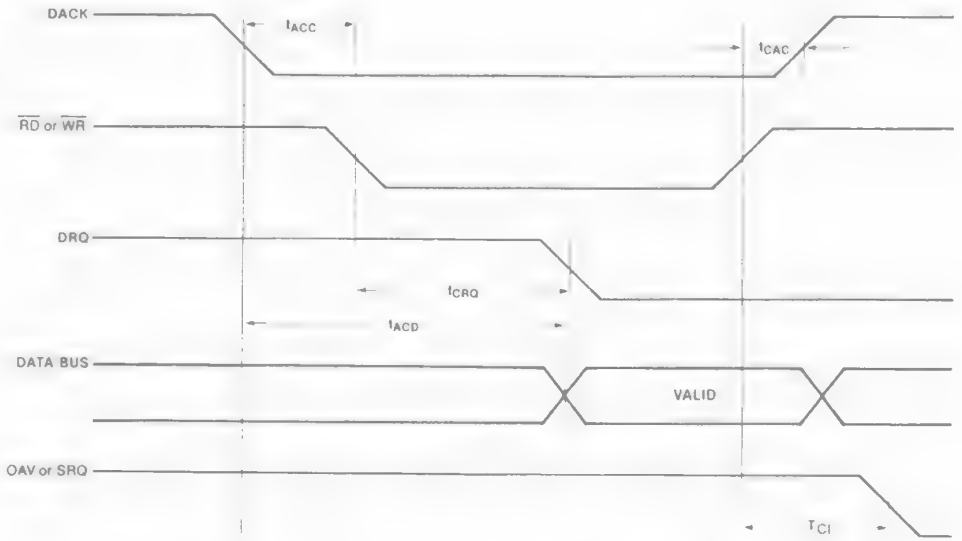
READ OPERATION—OUTPUT BUFFER REGISTER



WRITE OPERATION—INPUT BUFFER REGISTER



DMA AND INTERRUPT TIMING



AFN-00230D

8295
DOT MATRIX PRINTER CONTROLLER

- **Interfaces Dot Matrix Printers to MCS-48™, MCS-80/85™, MCS-86™ Systems**
- **40 Character Buffer On Chip**
- **Serial or Parallel Communication with Host**
- **DMA Transfer Capability**
- **Programmable Character Density (10 or 12 Chararcters/Inch)**
- **Programmable Print Intensity**
- **Single or Double Width Printing**
- **Programmable Multiple Line Feeds**
- **3 Tabulations**
- **2 General Purpose Outputs**

The Intel® 8295 Dot Matrix Printer Controller provides an interface for microprocessors to the LRC 7040 Series dot matrix impact printers. It may also be used as an interface to other similar printers.

The chip may be used in a serial or parallel communication mode with the host processor. In parallel mode, data transfers are based on polling, interrupts, or DMA. Furthermore, it provides internal buffering of up to 40 characters and contains a 7×7 matrix character generator accommodating 64 ASCII characters.

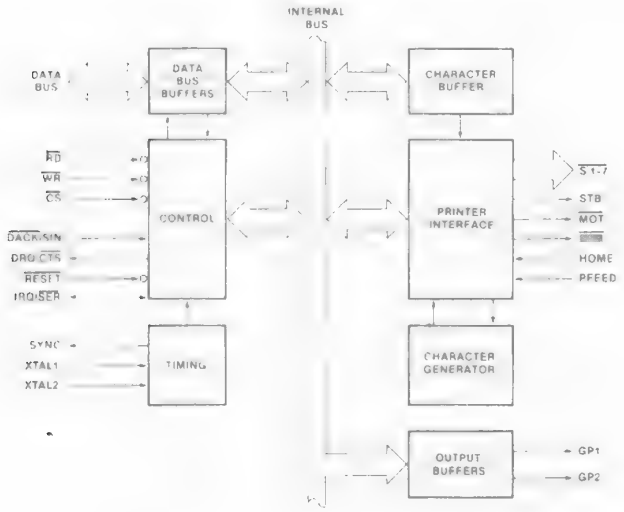


Figure 1. Block Diagram

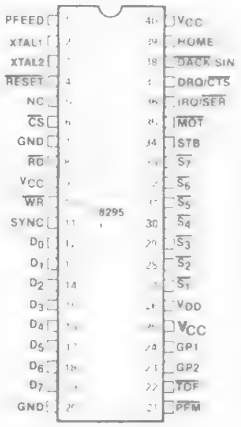


Figure 2. Pin Configuration

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
PFEED	1	I	**Paper Feed:** Paper feed input switch.
XTAL1 XTAL2	2 3	I	**Crystal:** Inputs for a crystal to set internal oscillator frequency. For proper operation use 6 MHz crystal.
$\overline{RESET}$	4	I	**Reset:** Reset input, active low. After reset the 8295 will be set for 12 characters/inch single width printing, solenoid strobe at 320 msec.
NC	5		**No Connection:** No connection or tied high.
$\overline{CS}$	6	I	**Chip Select:** Chip select input used to enable the RD and WR inputs except during DMA.
GND	7		**Ground:** This pin must be tied to ground.
$\overline{RD}$	8	I	**Read:** Read input which enables the master CPU to read data and status. In the serial mode this pin must be tied to V_{CC}.
V_{CC}	9		**Power:** +5 volt power input: +5V ± 10%.
$\overline{WR}$	10	I	**Write:** Write input which enables the master CPU to write data and commands to the 8295. In the serial mode this pin must be tied to V_{SS}.
SYNC	11	O	**Sync:** 2.5 μs clock output. Can be used as a strobe for external circuitry.
D_0 D_1 D_2 D_3 D_4 D_5 D_6 D_7	12 13 14 15 16 17 18 19	I/O	**Data Bus:** Three-state bidirectional data bus buffer lines used to interface the 8295 to the host processor in the parallel mode. In the serial mode D_0—D_2 sets up the baud rate.
GND	20		**Ground:** This pin must be tied to ground.
V_{CC}	40		**Power:** +5 volt power input: +5 ± 10%.

Symbol	Pin No.	Type	Name and Function
HOME	39	I	**Home:** Home input switch, used by the 8295 to detect that the print head is in the home position.
$\overline{DACK}$/SIN	38	I	**DMA Acknowledge/Serial Input:** In the parallel mode used as DMA acknowledgment; in the serial mode, used as input for data.
DRQ/$\overline{CTS}$	37	O	**DMA Request/Clear to Send:** In the parallel mode used as DMA request output pin to indicate to the 8257 that a DMA transfer is requested; in the serial mode used as clear-to-send signal.
IRQ/$\overline{SER}$	36	O	**Interrupt Request/Serial Mode:** In parallel mode it is an interrupt request input to the master CPU; in serial mode it should be strapped to V_{SS}.
$\overline{MOT}$	35	O	**Motor:** Main motor drive, active low.
STB	34	O	**Solenoid Strobe:** Solenoid strobe output. Used to determine duration of solenoids activation.
$\overline{S_7}$ $\overline{S_6}$ $\overline{S_5}$ $\overline{S_4}$ $\overline{S_3}$ $\overline{S_2}$ $\overline{S_1}$	33 32 31 30 29 28 27	O	**Solenoid:** Solenoid drive outputs; active low.
V_{DD}	26		**Power:** +5V power input (+5V ± 10%). Low power standby pin.
V_{CC}	25		**Power:** Tied high.
GP1 GP2	24 23	O O	**General Purpose:** General purpose output pins.
$\overline{TOF}$	22	I	**Top of Form:** Top of form input, used to sense top of form signal for type T printer.
$\overline{PFM}$	21	O	**Paper Feed Motor Drive:** Paper feed motor drive, active low.

FUNCTIONAL DESCRIPTION

The 8295 interfaces microcomputers to the LRC 7040 Series dot matrix impact printers, and to other similar printers. It provides internal buffering of up to 40 characters. Printing begins automatically when the buffer is full or when a carriage return character is received. It provides a modified 7x7 matrix character generator. The character set includes 64 ASCII characters.

Communication between the 8295 and the host processor can be implemented in either a serial or parallel mode. The parallel mode allows for character transfers into the buffer via DMA cycles. The serial mode features selectable data rates from 110 to 4800 baud.

The 8295 also offers two general purpose output pins which can be set or cleared by the host processor. They can be used with various printers to implement such functions as ribbon color selection, enabling form release solenoid, and reverse document feed.

COMMAND SUMMARY

Hex Code	Description
00	Set GP1. This command brings the GP1 pin to a logic high state. After power on it is automatically set high.
01	Set GP2. Same as the above but for GP2.
02	Clear GP1. Sets GP1 pin to logic low state, inverse of command 00.
03	Clear GP2. Same as above but for GP2. Inverse command 01.
04	Software Reset. This is a pacify command. This command is not effective immediately after commands requiring a parameter, as the Reset command will be interpreted as a parameter.
05	Print 10 characters/in. density.
06	Print 12 characters/in. density.
07	Print double width characters. This command prints characters at twice the normal width, that is, at either 17 or 20 characters per line.
08	Enable DMA mode; must be followed by two bytes specifying the number of data characters to be fetched. Least significant byte accepted first.
09	Tab character.
0A	Line feed.
0B	Multiple Line Feed; must be followed by a byte specifying the number of line feeds.
0C	Top of Form. Enables the line feed output until the Top of Form input is activated.
0D	Carriage Return. Signifies end of a line and enables the printer to start printing.
0E	Set Tab #1, followed by tab position byte.
0F	Set Tab #2, followed by tab position byte. Should be greater than Tab #1.
10	Set Tab #3, followed by tab position byte. Should be greater than Tab #2.
11	Print Head Home on Right. On some printers the print head home position is on the right. This command would enable normal left to right printing with such printers.
12	Set Strobe Width; must be followed by strobe width selection byte. This command adjusts the duration of the strobe activation.

PROGRAMMABLE PRINTING OPTIONS

CHARACTER DENSITY

The character density is programmable at 10 or 12 characters/inch (32 or 40 characters/line). The 8295 is automatically set to 12 characters/inch at power-up. Invoking the Print Double-Width command halves the character density (5 or 6 characters/inch). The 10 char/in or 12 char/in command must be re-issued to cancel the Double-Width mode. Different character density modes may not be mixed within a single line of printing.

PRINT INTENSITY

The intensity of the printed characters is determined by the amount of time during which the solenoid is on. This on-time is programmable via the Set Strobe-Width command. A byte following this command sets the solenoid on-time according to Table 2. Note that only the three least significant bits of this byte are important.

Table 2. Solenoid On-Time

D7—D3	D2	D1	D0	Solenoid On (microsec)
x	0	0	0	200
x	0	0	1	240
x	0	1	0	280
x	0	1	1	320
x	1	0	0	360
x	1	0	1	400
x	1	1	0	440
x	1	1	1	480

TABULATIONS

Up to three tabulation positions may be specified with the 8295. The column position of each tabulation is selected by issuing the Set Tab commands, each fol-

lowed by a byte specifying the column. The tab positions will then remain valid until new Set Tab commands are issued.

Sending a tab character (09H) will automatically fill the character buffer with blanks up to the next tab position. The character sent immediately after the tab character will thus be stored and printed at that position.

CPU TO 8295 INTERFACE

Communication between the CPU and the 8295 may take place in either a serial or parallel mode. However, the selection of modes is inherent in the system hardware; it is not software programmable. Thus, the two modes cannot be mixed in a single 8295 application.

PARALLEL INTERFACE

Two internal registers on the 8295 are addressable by the CPU: one for input, one for output. The following table describes how these registers are accessed.

$\overline{RD}$	$\overline{WR}$	$\overline{CS}$	Register
1	0	0	Input Data Register
0	1	0	Output Status Register

Input Data Register—Data written to this register is interpreted in one of two ways, depending on how the data is coded.

1. A command to be executed (0XH or 1XH).
2. A character to be stored in the character buffer for printing (2XH, 3XH, 4XH, or 5XH). See the character set, Table 2.

Output Status Register—8295 status is available in this register at all times.

STATUS BIT:	7	6	5	4	3	2	1	0
FUNCTION:	x	x	PA	DE	x	x	IBF	x

PA—Parameter Required; PA = 1 indicates that a command requiring a parameter has been received. After the necessary parameters have been received by the 8295, the PA flag is cleared.

DE—DMA Enabled; DE = 1 whenever the 8295 is in DMA mode. Upon completion of the required DMA transfers, the DE flag is cleared.

IBF—Input Buffer Full; IBF = 1 whenever data is written to the Input Data Register. No data should be written to the 8295 when IBF = 1.

A flow chart describing communication with the 8295 is shown in Figure 3.

The interrupt request output (IRQ, Pin 36) is available on the 8295 for interrupt driven systems. This output is asserted true whenever the 8295 is ready to receive data.

To improve bus efficiency and CPU overhead, data may be transferred from main memory to the 8295 via DMA cycles. Sending the Enable DMA command (08H) activates the DMA channel of the 8295. This command must be followed by two bytes specifying the length of the data string to be transferred (least significant byte first). The 8295 will then assert the required DMA requests to the 8257 DMA controller without further CPU intervention. Figure 4 shows a block diagram of the 8295 in DMA mode.

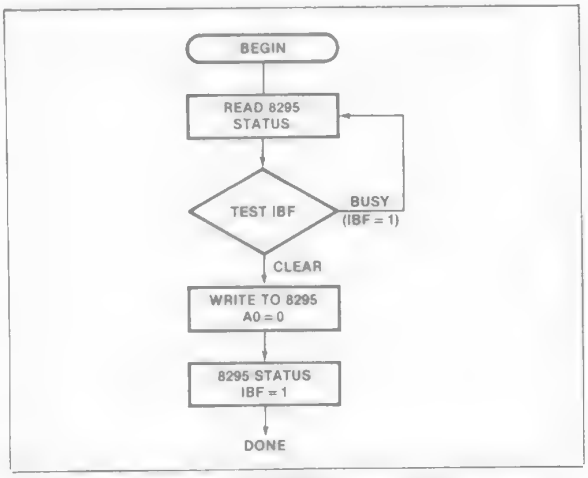


Figure 3. Host to 8295 Protocol Flowchart

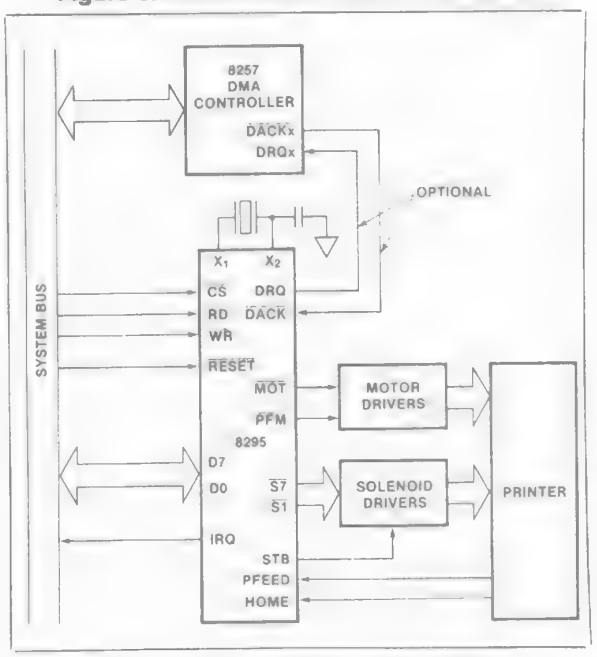


Figure 4. Parallel System Interface

Data transferred in the DMA mode may be either commands or characters or a mixture of both. The procedure is as follows:

1. Set up the 8257 DMA controller channel by sending a starting address and a block length.
2. Set up the 8295 by issuing the "Enable DMA" command (08H) followed by two bytes specifying the block length (least significant byte first).

The DMA enabled flag (DE) will be true until the assigned data transfer is completed. Upon completion of the transfer, the flag is cleared and the interrupt request (IRQ) signal is asserted. The 8295 then returns to the non-DMA mode of operation.

SERIAL INTERFACE

The 8295 may be hardware programmed to operate in a serial mode of communication. By connecting the IRQ/$\overline{SER}$ pin (pin 36) to logic zero, the serial mode is enabled immediately upon power-up. The serial Baud rate is also hardware programmable; by strapping pins 14, 13, and 12 according to Table 3, the rate is selected. $\overline{CS}$, $\overline{RD}$, and $\overline{WR}$ must be strapped as shown in Figure 5.

Table 3. Serial Baud Rate

Pin 14	Pin 13	Pin 12	Baud Rate
0	0	0	110
0	0	1	150
0	1	0	300
0	1	1	600
1	0	0	1200
1	0	1	2400
1	1	0	4800
1	1	1	4800

The serial data format is shown in Figure 5. The CPU should wait for a clear to send signal ($\overline{CTS}$) from the 8295 before sending data.

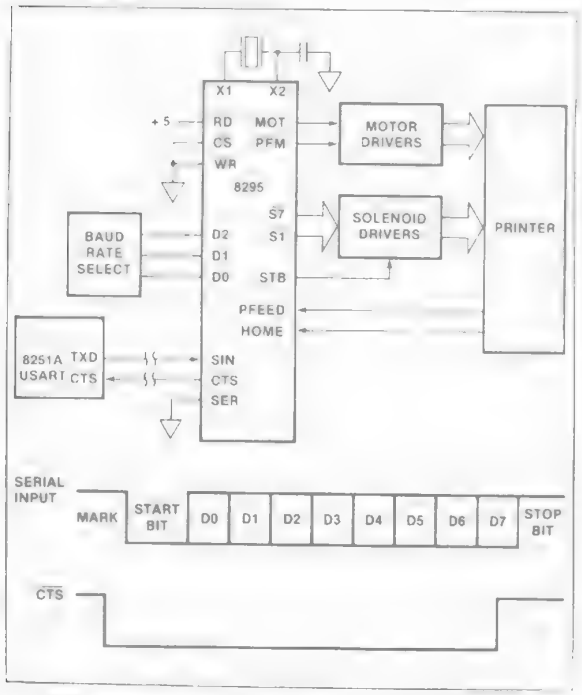


Figure 5. Serial Interface to UART (8251A)

8295 TO PRINTER INTERFACE

The strobe output signal of the 8295 determines the duration of the solenoid outputs, which hold the data to the printer. These solenoid outputs cannot drive the printer solenoids directly. They should be buffered through solenoid drivers as shown in Figure 6. Recommended solenoid and motor driver circuits may be found in the printer manufacturer's interface guide.

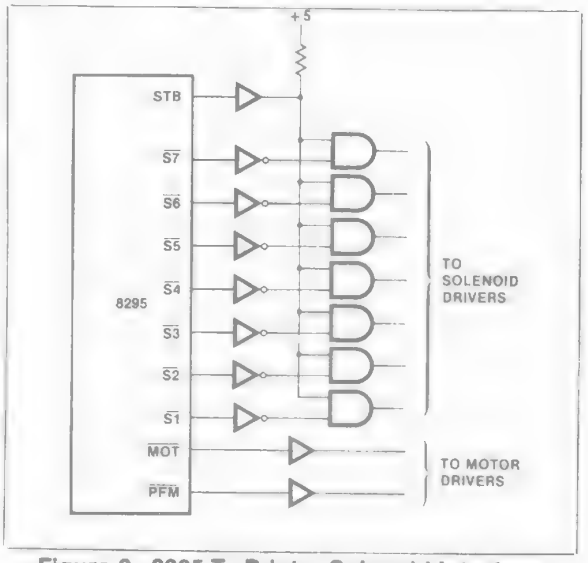


Figure 6. 8295 To Printer Solenoid Interface

OSCILLATOR AND TIMING CIRCUITS

The 8295's internal timing generation is controlled by a self-contained oscillator and timing circuit. A 6 MHz crystal is used to derive the basic oscillator frequency. The resident timing circuit consists of an oscillator, a state counter and a cycle counter as illustrated in Figure 7. The recommended crystal connection is shown in Figure 8.

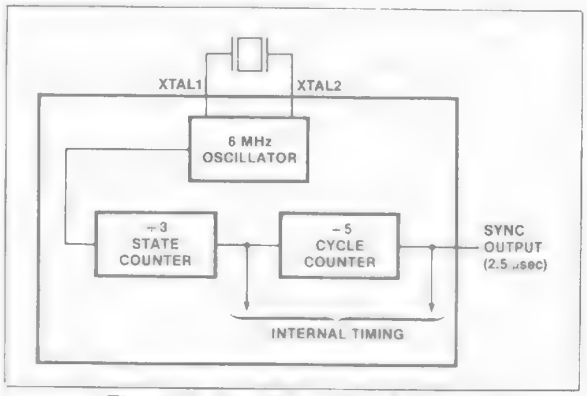


Figure 7. Oscillator Configuration

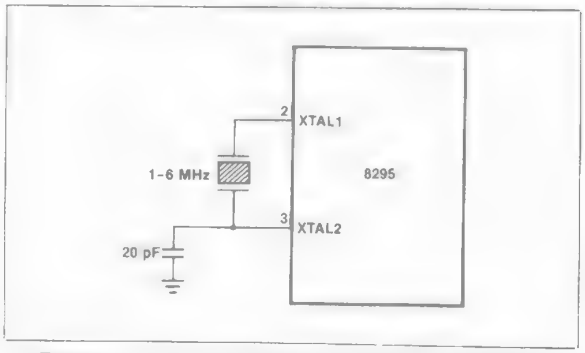


Figure 8. Recommended Crystal Connection

8295 CHARACTER SET

Hex Code	Print Char.	Hex Code	Print Char.	Hex Code	Print Char.	Hex Code	Print Char.
20	space	30	0	40	@	50	P
21	!	31	1	41	A	51	Q
22	"	32	2	42	B	52	R
23	#	33	3	43	C	53	S
24	$	34	4	44	D	54	T
25	%	35	5	45	E	55	U
26	&	36	6	46	F	56	V
27	'	37	7	47	G	57	W
28	(	38	8	48	H	58	X
29	)	39	9	49	I	59	Y
2A	*	3A	:	5A	J	5A	Z
2B	+	3B	;	4B	K	5B	[
2C	,	3C	<	4C	L	5C	\
2D	-	3D	=	4D	M	5D	]
2E	.	3E	>	4E	N	5E	↑
2F	/	3F	?	4F	O	5F	—

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias.....0°C to 70°C
Storage Temperature.....−65° to +150°C
Voltage on Any Pin With
Respect to Ground..... −0.5V to +7V
Power Dissipation.....1.5 Watt

**NOTICE: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

D.C. AND OPERATING CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = V_{DD} = +5V ± 10%, V_{SS} = 0V)

Symbol	Parameter	Limits			Unit	Test Conditions
		Min.	Typ.	Max.		
V_{IL}	Input Low Voltage (All Except X_1, X_2, $\overline{RESET}$)	−0.5		0.8	V	
V_{IL1}	Input Low Voltage (X_1, X_2, $\overline{RESET}$)	−0.5		0.6	V	
V_{IH}	Input High Voltage (All Except X_1, X_2, $\overline{RESET}$)	2.2		V_{CC}	V	
V_{IH1}	Input High Voltage (X_1, X_2, $\overline{RESET}$)	3.8		V_{CC}	V	
V_{OL}	Output Low Voltage (D_0–D_7)			0.45	V	I_{OL} = 2.0 mA
V_{OL1}	Output Low Voltage (All Other Outputs)			0.45	V	I_{OL} = 1.6 mA
V_{OH}	Output High Voltage (D_0–D_7)	2.4			V	I_{OH} = −400 μA
V_{OH1}	Output High Voltage (All Other Outputs)	2.4			V	I_{OH} = −50 μA
I_{IL}	Input Leakage Current ($\overline{RD}$, $\overline{WR}$, $\overline{CS}$, $\overline{A_0}$)			±10	μA	$V_{SS} \leq V_{IN} \leq V_{CC}$
I_{OFL}	Output Leakage Current (D_0–D_7, High Z State)			±10	μA	V_{SS}+0.45 ≤ V_{OUT} ≤ V_{CC}
I_{DD}	V_{DD} Supply Current		5	15	mA	
$I_{DD} + I_{CC}$	Total Supply Current		60	125	mA	
I_{LI}	Low Input Load Current (Pins 24, 27–38)			0.5	mA	V_{IL} = 0.8 V
I_{LI1}	Low Input Load Current ($\overline{RESET}$)			0.2	mA	V_{IL} = 0.8 V
I_{IH}	Input High Leakage Current (Pins 22, 38)			100	μA	V_{IN} = V_{CC}
C_{IN}	Input Capacitance			10	pF	
$C_{I/O}$	I/O Capacitance			20	pF	

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A.C. CHARACTERISTICS (T_A = 0°C to 70°C, V_{CC} = V_{DD} = +5V ± 10%, V_{SS} = 0V)

DBB READ

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AR}	$\overline{CS}$, A_0 Setup to $\overline{RD}$ ↓	0		ns	
t_{RA}	$\overline{CS}$, A_0 Hold After $\overline{RD}$ ↑	0		ns	
t_{RR}	$\overline{RD}$ Pulse Width	250		ns	
t_{AD}	$\overline{CS}$, A_0 to Data Out Delay		225	ns	C_L = 150 pF
t_{RD}	$\overline{RD}$ ↓ to Data Out Delay		225	ns	C_L = 150 pF
t_{DF}	$\overline{RD}$ ↑ to Data Float Delay		100	ns	
t_{CY}	Cycle Time	2.5	15	μs	

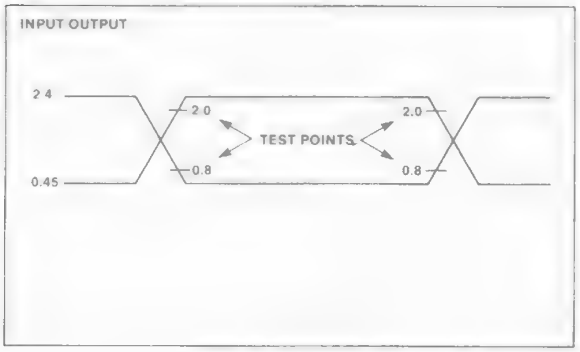
DBB WRITE

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{AW}	$\overline{CS}$, A_0 Setup to $\overline{WR}$ ↓	0		ns	
t_{WA}	$\overline{CS}$, A_0 Hold After $\overline{WR}$ ↑	0		ns	
t_{WW}	$\overline{WR}$ Pulse Width	250		ns	
t_{DW}	Data Setup to $\overline{WR}$ ↑	150		ns	
t_{WD}	Data Hold to $\overline{WR}$ ↑	0		ns	

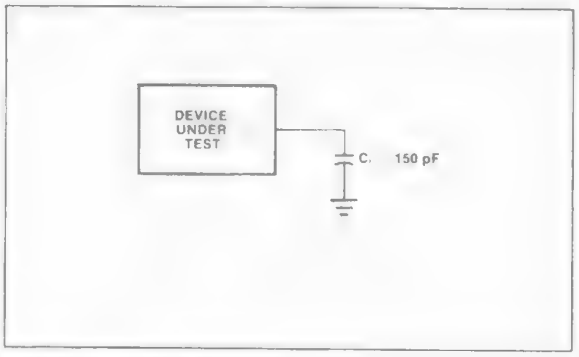
DMA AND INTERRUPT TIMING

Symbol	Parameter	Min.	Max.	Unit	Test Conditions
t_{ACC}	$\overline{DACK}$ Setup to Control	0		ns	
t_{CAC}	$\overline{DACK}$ Hold After Control	0		ns	
t_{CRQ}	$\overline{WR}$ to DRQ Cleared		200	ns	
t_{ACD}	$\overline{DACK}$ to Data Valid		225	ns	C_L = 150 pF

A.C. TESTING INPUT, OUTPUT WAVEFORM



A.C. TESTING LOAD CIRCUIT



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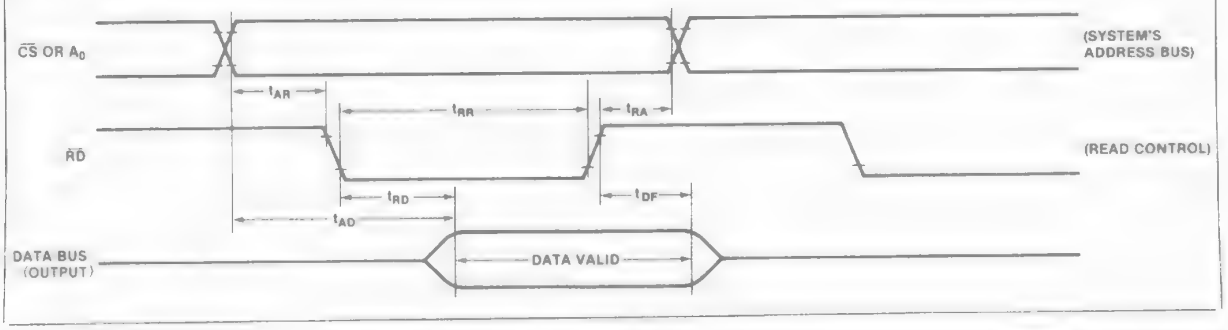
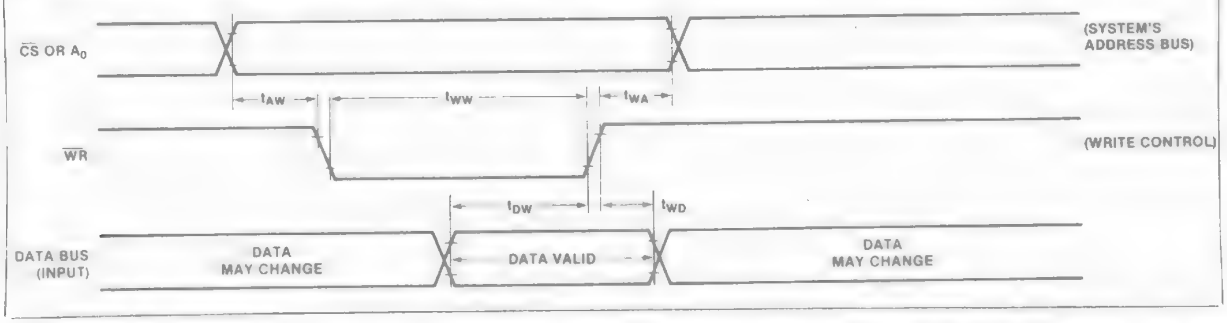
WAVEFORMS

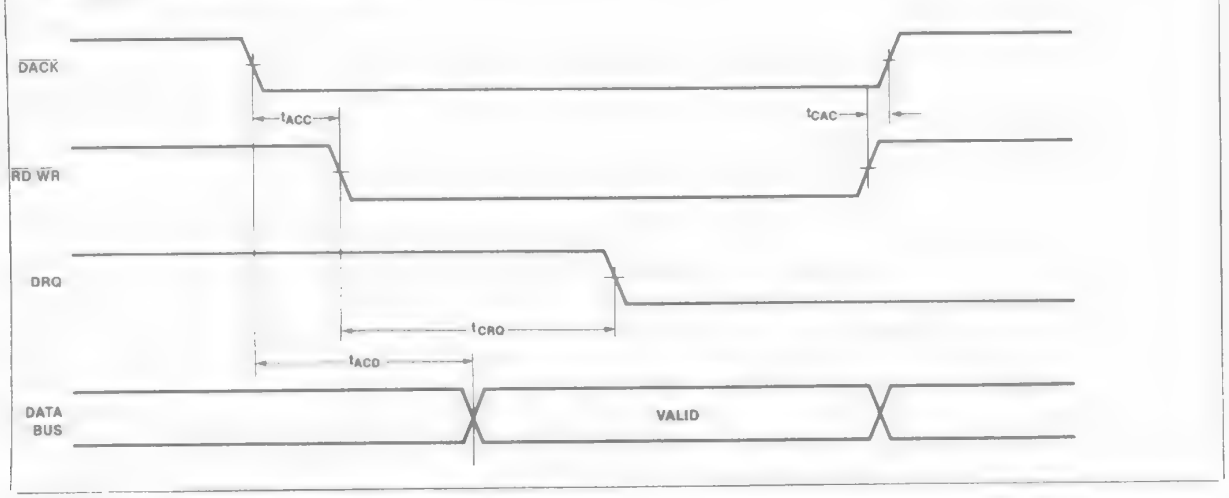
READ OPERATION—OUTPUT BUFFER REGISTER



WRITE OPERATION—INPUT BUFFER REGISTER



DMA AND INTERRUPT TIMING



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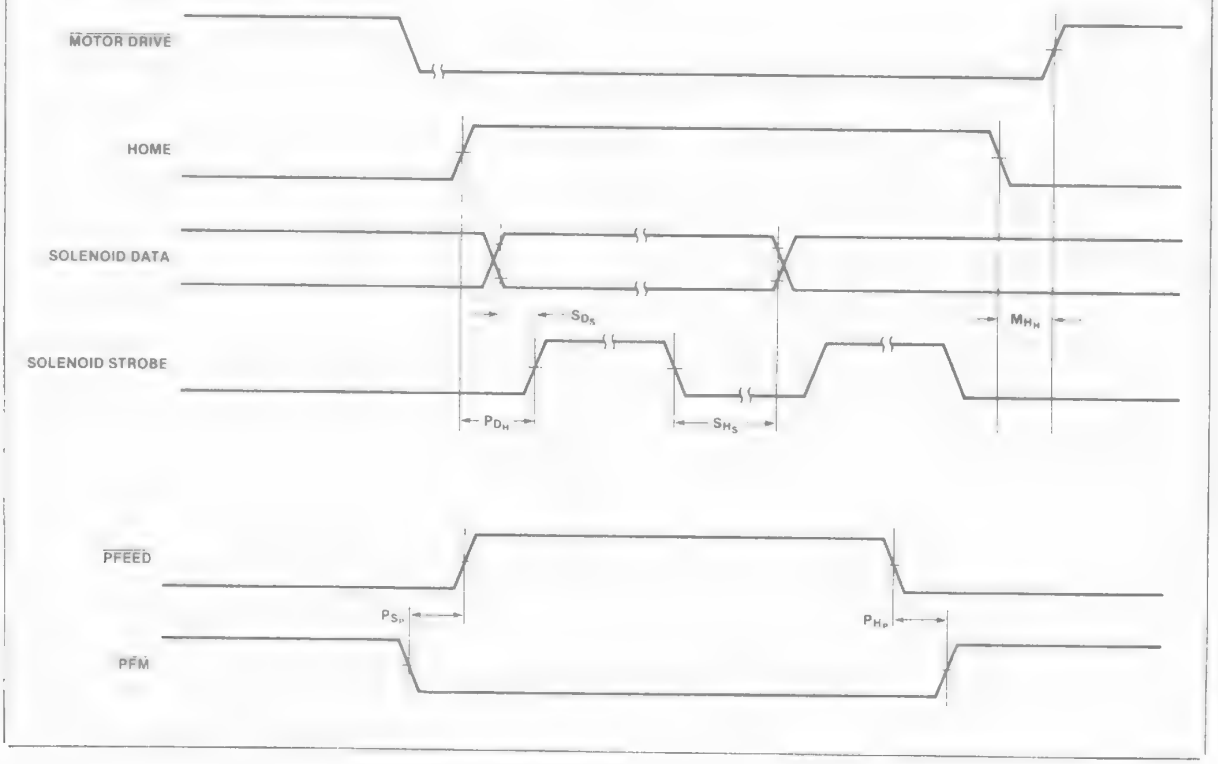
WAVEFORMS (Continued)

PRINTER INTERFACE TIMING



Symbol	Parameter	Typical
P_{DH}	Print delay from home inactive	1.8 ms
S_{DS}	Solenoid data setup time before strobe active	25 μs
S_{HS}	Solenoid data hold after strobe inactive	>1 ms
M_{HA}	Motor hold time after home active	3.2 ms
P_{SP}	PFEED setup time after PFM active	58 ms
P_{HP}	PFM hold time after PFEED active	9.75 ms

AFN-00231C

ADVANCE INFORMATION

82062
WINCHESTER DISK CONTROLLER

- Controls SA1000/ST506 Interface Winchester Drives
- 5 MBit/Sec Transfer Rate
- 128, 256, 512, and 1024 Byte Sector Lengths
- Six High-Level Commands: Restore, Seek, Read Sector, Write Sector, Scan ID, and Write Format
- Multiple Sector Transfer Capability
- Implied Seek With Read/Write Commands
- 7 Byte Sector Length Extension For External Error Correction Code
- Single +5 Volt Power Supply

The 82062 Winchester Disk Controller chip interfaces microprocessor systems to Winchester disks that use the Shugart Associates SA1000 or Seagate Technology ST506 interface. Examples include Seagate ST506 and ST512, Shugart SA1000, SA1100, and SA600, Tandon 600, Texas Instruments 506, RMS 500, and Quantum Q2000. The device translates parallel data from the microprocessor to a 5 mbit/sec, MFM-encoded serial bit stream. It provides all the drive control logic and, in addition, control signals which simplify the design of an external phase locked loop and write precompensation circuitry. The 82062 is designed to interface to the host controller through an external sector buffer.

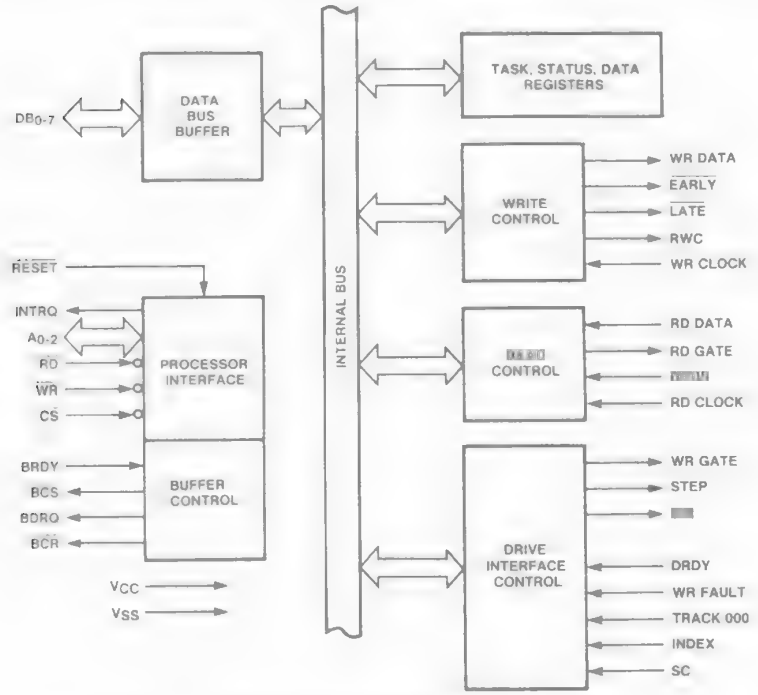


Figure 1. 82062 Internal Block Diagram

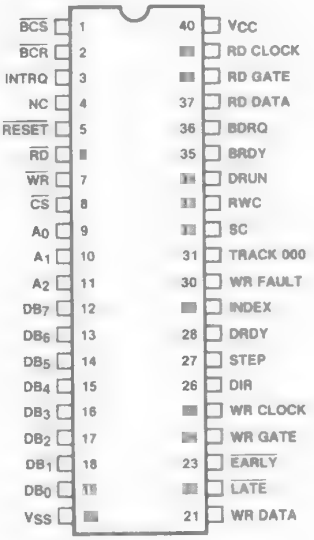


Figure 2. Pin Configuration

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FUNCTIONAL DESCRIPTION

The 82062 Winchester Disk Controller integrates much of the logic needed to implement Winchester disk controller subsystems. It provides MFM-encoded data and all the control lines required by hard disks using the Seagate Technology ST506 or Shugart Associates SA1000 interface standard. Currently, most 5-1/4 inch and many 8 inch Winchester drives use this interface.

Due to the higher data rates required by these drives—1 byte every 1.6 usec—the 82062 is designed to interface with the host CPU or I/O controller through an external buffer RAM. The 82062 WDC has four pins that minimize the logic required to design a buffer interface.

Figure 3 shows a block diagram of an 82062 subsystem. The WDC is controlled by the host CPU through six commands:

Restore
Seek
Read Sector
Write Sector
Scan ID
Write Format

These commands use information stored by six task registers. Command execution starts immediately after the command register is loaded—therefore commands require only one byte from the CPU after the WDC has been initialized.

The 82062 adds all the required track formatting to the data field, including two bytes of CRC. Optionally, these two bytes can be replaced by seven bytes of ECC information for external error correction.

PROCESSOR INTERFACE

Figure 4 shows one possible hardware interface between the WDC and the host CPU or I/O controller. For initializing the 82062, the host uses the standard peripheral interface lines: $\overline{RD}$, $\overline{WR}$, $\overline{CS}$, and A_{0-2}. For read and write cycles, the host and the WDC exchange data through an external RAM buffer. The WDC has four pins, $\overline{BCR}$, $\overline{BCS}$, BRDY, and BDRQ, that facilitate the design of the buffer interface.

The processor starts disk operations by initializing the WDC. It first writes the appropriate parameters into the task register file. The task information includes the drive number, cylinder, head, and sector numbers, sector size, number of sectors to be transferred, and the track number for write precompensation to start. After the task information, the command is written to the command register. See the 82062 Register-CPU Interface section for more details.

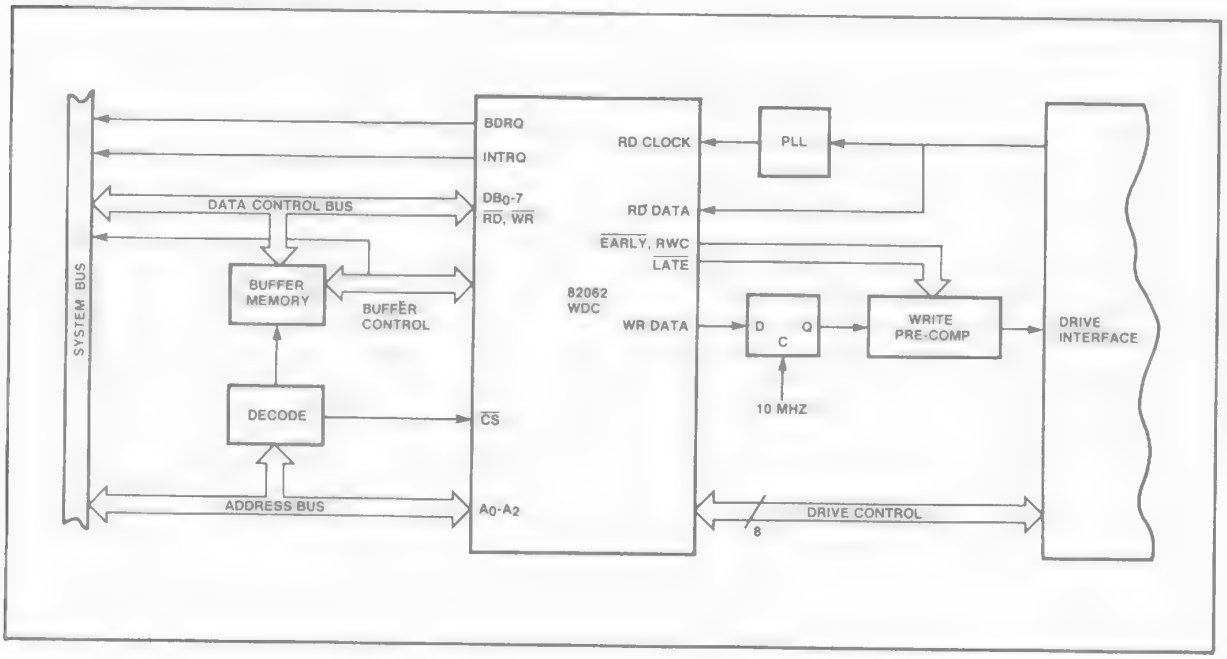

Figure 3. System Block Diagram

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Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
DB_7-DB_0	12-19	I/O	**Data Bus**: Bidirectional 8-bit Data Bus
$\overline{RESET}$	5	I	**Reset**: Initializes the controller and clears all status flags.
$\overline{RD}$	6	I/O	**Read**: As an input, $\overline{RD}$ controls the transfer of status information from the WDC to the host. $\overline{RD}$ is an output for reading data from the sector buffer.
$\overline{WR}$	7	I/O	**Write**: As an input, $\overline{WR}$ controls the transfer of command or task information into the WDC. $\overline{WR}$ is an output for writing data to the sector buffer.
$\overline{CS}$	8	I	**Chip Select**: Enables $\overline{RD}$ or $\overline{WR}$ as inputs.
A_0-A_2	9-11	I	**Address**: Used to select a register from the task register file.
INTRQ	3	O	**Interrupt Request**: Interrupt generated by the WDC upon command termination. It is reset when the status register is read.
$\overline{BCS}$	1	O	**Buffer Chip Select**: Output used to enable reading or writing of the external sector buffer.
$\overline{BCR}$	2	0	**Buffer Counter Reset**: Can be optionally used to reset the address counter of the buffer memory. Activated by Read and Write Commands.
BRDY	35	I	**Buffer Ready**: Input used by the buffer memory to signal the controller that it is ready for reading (full) or writing (empty). BRDY is checked during Read and Write commands.
BDRQ	36	O	**Buffer Data Request**: Optionally activated during Read or Write commands if BRDY is high. Can be used as a DMA Request line.
WR DATA	21	O	**Write Data**: Open drain output that shifts out MFM data at a rate determined by the Write Clock input.
$\overline{LATE}$	22	O	**Late**: Open drain output used to derive a delay value for write precompensation. Valid when the WR GATE output is high.
$\overline{EARLY}$	23	O	**Early**: Open drain output used to derive a delay value for write precompensation. Valid when the WR GATE output is high.
WR GATE	24	O	**Write Gate**: High when write data is valid. WR GATE goes low if the WF input is high. This output is used by the drive to enable head write current.
WR CLOCK	25	I	**Write Clock**: Clock input used to derive the write data rate. Frequency = 5MHz for the ST500 interface, 4.34MHz for the SA 1000 interface.
RWC	33	O	**Reduced Write Current**: Signal goes high for all cylinder numbers above the value programmed to the Write Precomp Cylinder register. It is used by the precompensation logic and by the drive.
DRUN	34	I	**Data Run**: Looks for a string of zeros in the read data, indicating the beginning of an ID field. If the zeros are detected, RD GATE is brought high.
RD DATA	37	I	**Read Data**: Accepts MFM data from the drive.
RD GATE	38	O	**Read Gate**: Output that is high for data and ID fields.
RD CLOCK	39	I	**Read Clock**: Clock input derived from the external data recovery circuits
DIR	26	O	**Direction**: High level on this output tells the drive to move inward (increasing cylinder number). The signal is determined by the WDC commands.
STEP	27	O	**Step**: Provides 6.4 microsecond pulses to move the drive head to another cylinder.
DRDY	28	I	**Drive Ready**: If DRDY from the drive goes low, all commands will be deactivated.
INDEX	29	I	**Index**: Signal from the drive indicating the beginning of a track. It is used by the WDC during formatting.
WR FAULT	30	I	**Write Fault**: If WR FAULT from the drive goes low, all commands will be deactivated.
TRACK 000	31	I	**Track Zero**: Used by the Restore command to verify that the head is at the outermost cylinder.
SC	32	I	**Seek Complete**: Signal from the drive indicating that reads or writes can be made.
VSS	20	I	**Ground**
VCC	40	I	**D.C. Power**: +5V

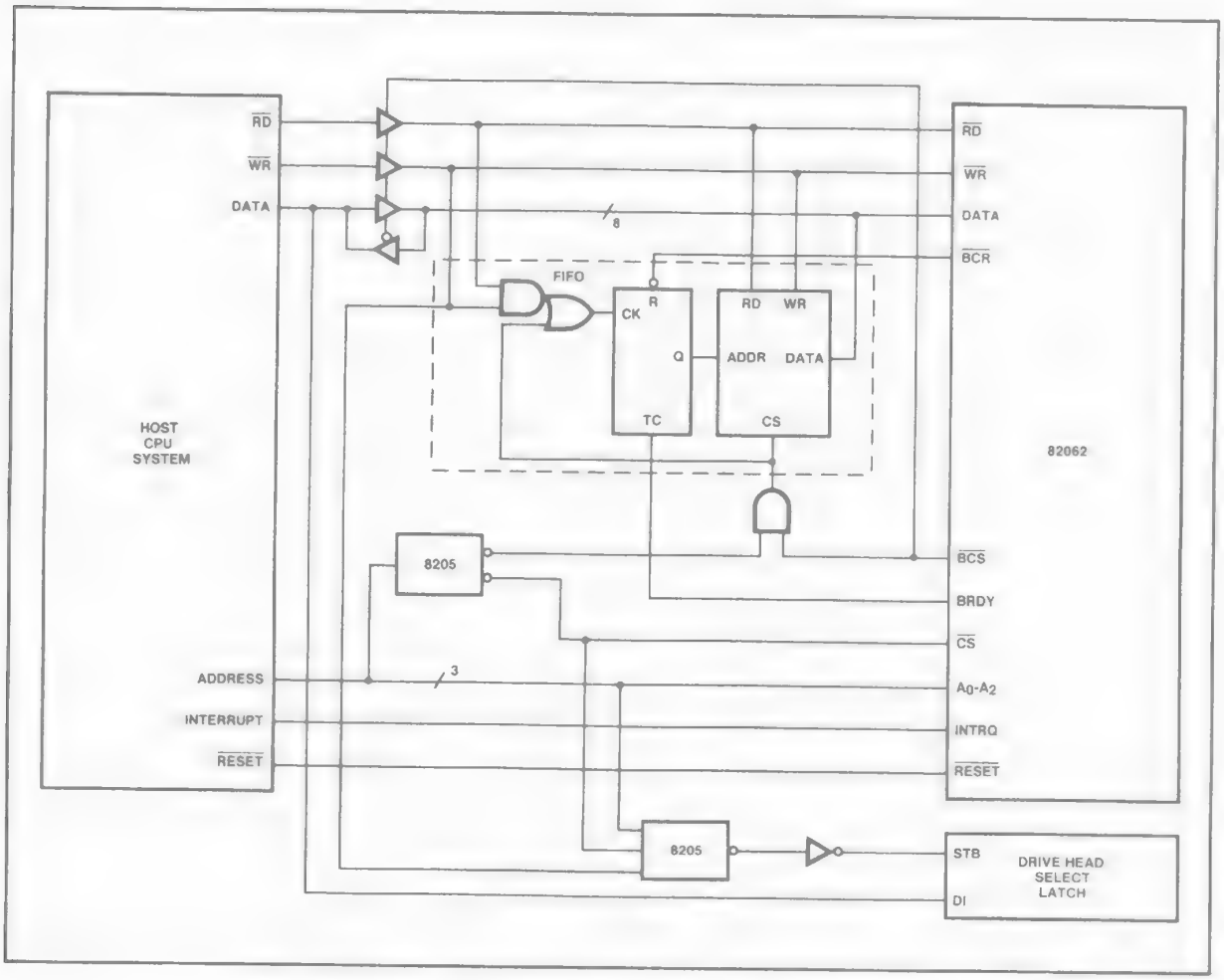

Figure 4. CPU Buffer Interface

For example, in the case of a Write Sector command, the processor would first read the WDC status register. It would then write data to the buffer memory. When the buffer is full, it sets the BRDY line to the WDC, which then resets (low) the buffer data request (BDRQ) output and sets (low) the buffer chip select ($\overline{BCS}$) line. The $\overline{BCS}$ signal is used to both select the buffer and to isolate the host system control lines. At this point the 82062 $\overline{WR}$ pin is an output and it reads the data from the buffer into the WDC where it is formatted and encoded and sent to the disk. When the buffer memory is empty, the BRDY line signals the WDC to bring $\overline{BCS}$ high, thus allowing the host CPU to write more data or give another command.

COMMAND DESCRIPTION

Command : RESTORE

Format : 0 0 0 0 R_3 R_2 R_1 R_0

Description : The step rate specified by R_3 R_2 R_1 R_0 is loaded into the step rate register. Stepping pulses are transmitted with the DIR output low.

Command Flow :
1. Abort if drive not ready or write fault.
2. Wait for up to 3 index pulses for seek complete.
3. If TK000 active, then go to 6.
4. Step outwards; if number of steps exceeds 1024, then abort.
5. Wait for seek complete; go to 3.
6. End.

Command : SEEK

Format : 0 1 1 0 R_3 R_2 R_1 R_0

Description : Seeks the cylinder specified in cylinder number register with a step rate specified by R_3 R_2 R_1 R_0. Present cylinder position information is kept for the current drive. Controller does not wait for seek complete at end of comand, thus allowing overlapped seeks with the SA1000 drive.

Command Flow :
1. Abort if drive not ready or write fault.
2. Wait for seek complete.
3. Calculate direction and number of step pulses.
4. Update internal present cylinder position number register.
5. Send step pulses at rate specified by R_3 R_2 R_1 R_0.
6. Wait for seek complete, verify head and sector numbers. End.

Command : READ SECTOR

Format : 0 0 1 0 I M 0 0

Description : Seek track if desired cylinder different from present location. If M = 0, then the sector specified in sector number register is read. If M = 1, then multiple records are read, starting with the sector specified by the sector number register and continuing in sequential order until the number of sectors specified in the sector count register are read. If I = 0, interrupt at activation of BDRQ. If I = 1, interrupt at end of command.

Command Flow :
1. Abort if drive not ready or write fault.
2. Activate $\overline{BCS}$.
3. Seek track if necessary using step rate of last Restore or Seek command.
4. Wait for SC active.
5. Activate $\overline{BCR}$ pin. Search for head, cylinder, sector number and size.
6. When the proper sector ID is found, read sector data.
7. If BRDY pin activated at end of sector data transfer to buffer memory, set DRQ flag, activate BDRQ pin and interrupt if I = 0. Wait for BRDY pin activation indicating empty buffer.
8. If M = 0, then set BDRQ flag, activate BDRQ pin, wait for BRDY, end.
9. Decrement sector count, increment sector number. If M = 1 and sector count = 0, then go to 10 else search for next sector and go to 6.
10. If I = 0 then interrupt; end.

Command : WRITE SECTOR

Format : 0 0 1 1 0 M 0 0

Description : Seek track if necessary. Write from buffer to disk when BRDY pin activated. Write total number of sectors specified by sector count register if M = 1. Sectors are written in numerical order. If M = 0, then sector count is ignored and only one sector is written.

Command Flow :
1. Abort if drive not ready or write fault
2. Activate $\overline{BCR}$ pin.
3. Seek track if necessary.
4. Wait for SC pin active.
5. Activate BDRQ pin, set DRQ flag, interrupt. Wait for BRDY active.
6. Search for ID field and write sector.
7. If M = 0, then end.
8. Increment sector number, decrement sector count.
9. If sector count = 0, then end.
10. If BRDY activated at end of sector data transfer from buffer memory, then go to 6. Otherwise go to 7.

Command : SCAN ID

Format : 0 1 0 0 0 0 0 0

Description : When the next ID field of the present track is encountered, cylinder number, sector size, head number and sector number are loaded into the respective registers.

Command Flow :
1. Abort if drive not ready or write fault at any time.
2. Search for next ID field and read 3 ID bytes into respective registers.
3. Update internal present cylinder location number register. End.

Command : WRITE FORMAT

Format : 0 1 0 1 0 0 0 0

Description : This command formats one track using parameters loaded in the task register file and in buffer memory. The track format is shown in Figure 6.

Cylinder, head, sector extension and sector size number are taken from the Task Register file. Good block/bad block marks and sector numbers are taken from buffer memory. The total number of sectors formatted is specified by the sector count register. The lengths of GAP 1 and GAP 3 are loaded into the sector number register. These gaps are recorded as $4E_{16}$.

After the task register file has been loaded with the desired format parameters and the command register has been loaded with the write format command, the block marks and sector addresses are loaded into the buffer. When the BRDY pin is activated, the specified number of sectors are written. The block marks and sector numbers are read from the buffer as needed. The data field is written with $E5_{16}$. CRC is automatically computed and written.

Command Flow :
1. Abort if drive not ready or write fault at any time.
2. Activate BCR.
   Set BDRQ flag, activate BDRQ, interrupt. Wait for DRDY active. Wait for SC.
3. Write index gap after index pulse received.
4. If sector count = 0, go to 7.
5. Write sector using parameters in task register file and buffer meory.
6. Decrement sector count register; go to 4.
7. Write 4E's until index pulse.
8. Read from buffer until empty (BRDY received). End

Table 2. Register File

A_2	A_1	A_0	Read Operation	Write Operation
1	1	1	Status	Command
1	1	0	Sector-Drive-Head	Sector-Drive-Head
1	0	1	Cylinder Number HIgh	Cylinder Number High
1	0	0	Cylinder Number Low	Cylinder Number Low
0	1	1	Sector Number	Sector Number
0	1	0	Sector Count	Sector Count
0	0	1	Error Flags	Write Precomp Cylinder
0	0	0	Data	Data

82062 REGISTER-CPU INTERFACE

The 82062 communicates with the host CPU through a task register file of seven registers. Table 2 illustrates these registers and the control signals to select them. Following is a description of each of these registers:

Status Register

Bit No.	Name	Symbol	Description
DB_0	Error	ERR	A bit in the error register has been set.
DB_1	Command in progress	CIP	WDC is currently executing a command.
DB_2	—	—	Reserved.
DB_3	Data Request	DRQ	Reflects the state of the BDRQ pin. Indicates that a buffer data transfer is desired. In a system, this flag is typically used for programmed I/O.
DB_4	Seek Complete	SC	Reflects the state of the SC input pin. The bit is latched at the end of a command until the status register is read.
DB_5	Write Fault	WF	Reflects the state of the WF pin. An interrupt is generated by the INTRQ pin when this bit is set. The bit is latched at the end of a command until the status register is read.
DB_6	Drive Ready	DRR	Reflects the state of the DRDY pin. However, after an error interrupt the state of DRR is held until the status register is read. When DRR goes low, an interrupt is generated.

Status Register

Bit No.	Name	Symbol	Description
DB_7	Busy	BUSY	Set by writing into the command register. Reset at the end of all commands except Read Sector. For the Read Sector Command, BUSY is reset after a sector of data is transferred to the buffer.

Command Register

Command	DB_7	DB_6	DB_5	DB_4	DB_3	DB_2	DB_1	DB_0
Restore	0	0	0	1	R_3	R_2	R_1	R_0
Seek	0	1	1	1	R_3	R_2	R_1	R_0
Read Sector	0	0	1	0	I	M	0	0
Write Sector	0	0	1	1	0	M	0	0
Scan ID	0	1	0	0	0	0	0	0
Write Format	0	1	0	1	0	0	0	0

I = 0 INTRQ goes active when BDRQ goes active.
= 1 INTRQ goes active upon command termination.

M = 1 Multiple sector read or write.

R_3, R_2, R_1, R_0 = 0000 Step time = 20 usec at 5MHz WR CLOCK
= 0001 Step time = 0.5 msec
= 0010 Step time = 1.0 msec
= 0011 Step time = 1.5 msec
. .
. .
. .
= 1111 Step time = 7.5 msec

Sector-Drive-Head Register

Bit No.	Name	Symbol	Description
DB_{0-2}	Head Number	HDN	Used internally for formatting and ID field comparing.
DB_{3-4}	Drive Number	DRN	Used internally. If the drive number is changed between commands, then an automatic Read ID command is performed before seeking.
DB_{5-6}	Bytes per sector	BPS	DB_6 DB_5 1 1 128 byte sector 0 0 256 byte sector 0 1 512 byte sector 1 0 1024 byte sector
DB_7	Sector extension	SE	DB_7 = 1 tells the WDC to substitute a 7-byte ECC code for the 2-byte CRC field.

CYLINDER NUMBER REGISTERS

Two registers hold the cylinder number that can range from 0 to 1023. During seek operations, an internal present position register is compared to the Cylinder Number register to determine the DIR output and the number of step pulses.

SECTOR NUMBER REGISTERS

This register has two multiplexed functions. For Read Sector and Write Sector Commands, this register holds on 8-bit binary value that corresponds to the sector address in the ID field. For the Write Format command, it holds an 8 bit binary value that specifies the number of bytes in both Gap 1 and Gap 3.

SECTOR COUNT REGISTER

This register hold an 8-bit value that determines the number of sectors for multiple sector commands (Read sector, Write Sector, or Format). A value of 1 indicates a single sector, while 0 indicates a 256 sector transfer. The value is decremented for each sector handled during the command.

Error Flags Register

Bit No.	Name	Symbol	Description
DB_0	AM Not Found	AMNF	During a read operation, the desired ID field was found, but the data field address mark was not found.
DB_1	TK000 Error	TK0E	Track zero was not found after 1024 steps in the Restore command.
DB_2	Aborted Command	AC	A command was started and one of the following occurred: 1) Drive not ready; 2) Write fault; 3) SC input not active within 16 index pulses; or 4) an illegal command code was received.
DB_3	—	—	Not used.
DB_4	ID Not Found	IDNF	ID field parameters (cylinder, head, sector) not found within 3 index pulses.
DB_5	—	—	Not used.

Error Flags Register

Bit No.	Name	Symbol	Description
DB_6	Data Field CRC Error	DFE	An error in the data field was detected by the CRC. The sector may be re-read.
DB_7	Bad block	BB	A bad block address mark was detected during a read or write operation. An interrupt is generated depending upon the I bit in the command.

WRITE PRECOMP CYLINDER REGISTER

This register holds a value from 0 to 256. The reduced write current pin (RWC) is high when the Cylinder register value is greater than or equal to four times the write Precomp Cylinder register value.

DRIVE INTERFACE DESCRIPTION

The 82062 provides the control lines to interface to ST506/SA1000 interface drives. It contains a high speed shift register, an MFM encoder/decoder, and an address mark detector. Signals are provided to control write precompensation and write splice avoidance. External circuitry must be used for the phase locked MFM read clock and the head/drive selection. Figure 5 shows a typical controller-drive interface for a system with two Winchester drives. Figure 6 shows the track formatting used by the 82062.

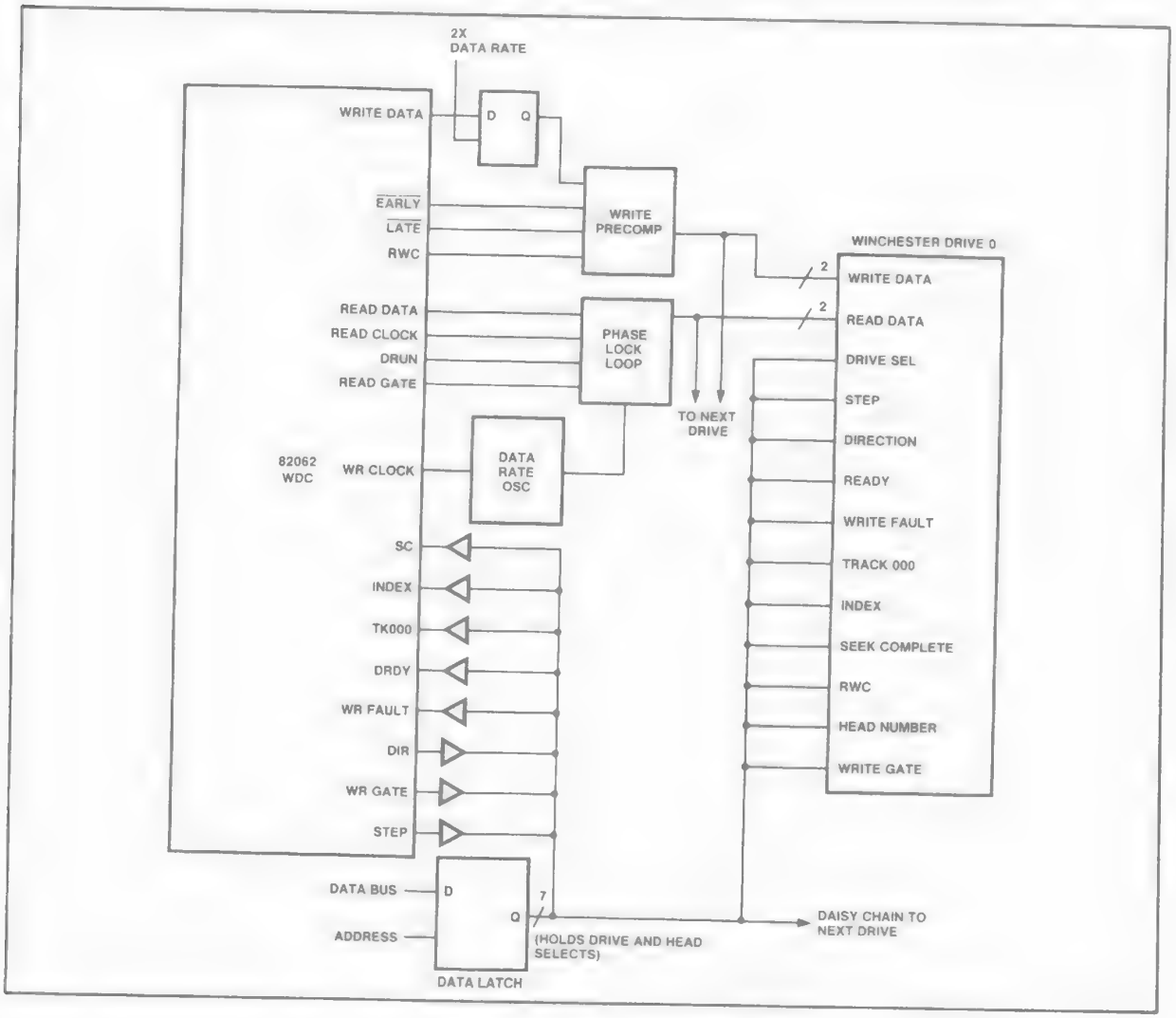

Figure 5. Drive Interface

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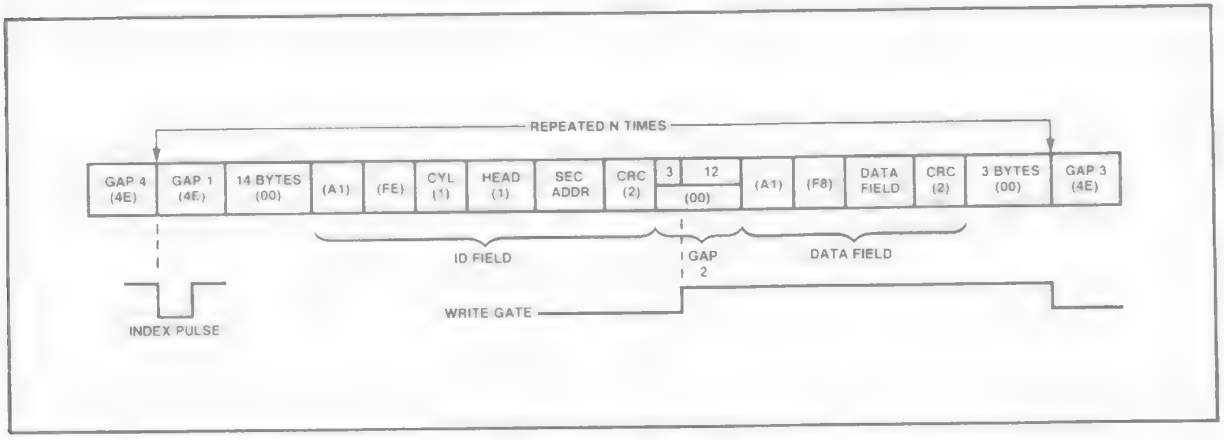

Figure 6. Track Format

ADVANCE INFORMATION

82501 ETHERNET SERIAL INTERFACE

- Compatible with the Ethernet* Specification
- 10-Mbs Operation
- Replaces 8 to 12 MSI Components
- Manchester Encoding/Decoding and Receive Clock Recovery
- 10-MHz Transmit Clock Generator
- Driving/Receiving Ethernet Transceiver Cable
- Fail-Safe Watchdog Timer Circuit to Prevent Continuous Transmissions
- Diagnostics Loopback for Fault Detection and Isolation
- Directly Interfaces to the 82586 Controller

The 82501 Ethernet Serial Interface (ESI) chip is designed to work directly with the 82586 controller in Ethernet and non-Ethernet 10-Mbps local-area network applications. The major functions of the 82501 are to generate the 10 MHz transmit clock for the 82586, perform Manchester encoding/decoding of transmitted/received frames, and provide the electrical interface to the Ethernet transceiver cable. Diagnostic loopback control enables the 82501 to route the signal to be transmitted from the 82586 through its Manchester encoding and decoding circuitry and back to the 82586. The combined loopback capabilities of the 82586 and 82501 result in efficient fault detection and isolation by providing sequential testing of the communications interface. An on-chip fail-safe watchdog timer circuit prevents the station from locking up in a continuous transmit mode.

*Ethernet is a trademark of Xerox Corporation.

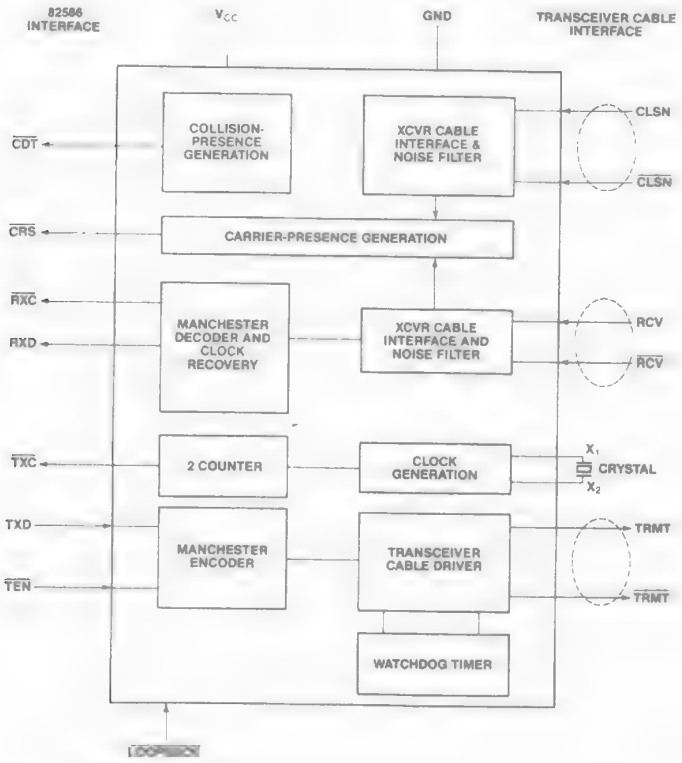

Figure 1. 82501 Functional Block Diagram

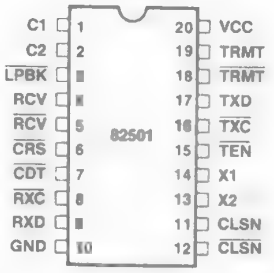

Figure 2. Pin Configuration

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ORDER NUMBER: 210783-001

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Function
$\overline{TXC}$	16	O	**Transmit Clock:** A 10-MHz clock output with 5 nsec rise and fall times and MOS driving levels. This clock is provided to the 82586 for serial transmission.
$\overline{TEN}$	18	I	**Transmit Enable:** An active low, TTL-level signal synchronous to $\overline{TXC}$ that enables data transmission to the transceiver cable. $\overline{TEN}$ can be driven by $\overline{RTS}$ from the 82586.
TXD	17	I	**Transmit Data:** A TTL-level input signal that is directly connected to the serial data ouput, TXD, of the 82586.
$\overline{RXC}$	8	O	**Receive Clock:** An MOS-level clock output with 5 nsec rise and fall times and 50% duty cycle. This output is connected to the 82586 receive clock input $\overline{RXC}$. There is a maximum 1.2 μsec discontinuity at the beginning of a frame reception when the phase-locked loop switches from the on-chip oscillator to the incoming data. During idle (no incoming frames) the clock frequency will be half that of the 20 MHz crystal frequency.
$\overline{CRS}$	6	O	**Carrier Sense:** A TTL-level, active low output to notify the 82586 that there is activity on the coaxial cable. This signal is asserted when valid data or a collision signal from the transceiver is present. It is deasserted at the end of a frame synchronous with $\overline{RXC}$, or when the end of the collision-presence signal (CLSN and $\overline{CLSN}$) is detected, whichever occurs later. Once deasserted, $\overline{CRS}$ will not be reasserted again for a period of 5 μsec minimum, 7 μsec maximum, regardless of any activity on the receive or collision-presence pairs.
RXD	[illegible]	O	**Receive Data:** An MOS-level output tied directly to the RXD input of the 82586 controller and sampled by the 82586 at the negative edge of $\overline{RXC}$. The bit stream received from the transceiver cable is Manchester decoded prior to being transferred to the controller. This output remains high during idle.
$\overline{CDT}$	7	O	**Collision Detect:** A TTL, active low signal which drives the $\overline{CDT}$ input of the 82586 controller. It is asserted as long as there is activity on the collision-presence pair (CLSN and $\overline{CLSN}$).
$\overline{LPBK}$	3	I	**Loopback:** A TTL-level control signal to enable the loopback mode. In this mode, serial data on the TXD input is routed through the 82501 internal circuits and back to the RXD output without driving the TRMT/$\overline{TRMT}$ output pair to the transceiver cable. When $\overline{LPBK}$ is asserted, the collision circuit will also be turned on at the end of each transmission to simulate the collision test.
TRMT $\overline{TRMT}$	19 18	O O	**Transmit Pair:** An output driver pair which generates the differential signal for the transmit pair of the Ethernet transceiver cable. Following the last transition, which is always positive at TRMT, the differential voltage is slowly reduced to zero volts. The output stream is Manchester encoded.
RCV $\overline{RCV}$	4 [illegible]	I I	**Receive Pair:** A differentially driven input pair which is tied to the receive pair of the Ethernet transceiver cable. The first transition on RCV will be negative-going to indicate the beginning of a frame. The last transition should be positive-going, indicating the end of a frame. The received bit stream is assumed to be Manchester encoded.
CLSN $\overline{CLSN}$	12 11	I I	**Collision Pair:** A differentially driven input pair tied to the collision-presence pair of the Ethernet transceiver cable. The collision-presence signal is a 10 MHz ±15% square wave. The first transition at CLSN is negative-going to indicate the beginning of the signal; the last transition is positive-going to indicate the end of the signal.
C1 C2	1 2	I I	**PLL Capacitor:** Phase-locked-loop capacitor inputs.
X_1 X_2	14 15	I I	**Clock Crystal:** 20-MHz crystal inputs.
V_{CC}	20		**Power:** 5 ±5% volts.
GND	10		**Ground:** Reference.

FUNCTIONAL DESCRIPTION

Clock Generation

A 20 MHz crystal-controlled oscillator is provided as the basic clock source. This 20 MHz signal is then

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divided by 2 to generate a 10 MHz ± .01% clock as required in the Ethernet specification.

Manchester Encoder and Transceiver Cable Driver

The 20 MHz clock is used to Manchester encode data on the TXD input line. The clock is also divided by 2 to produce the 10 MHz clock required by the 82586 for synchronizing its $\overline{RTS}$ and TXD signals. See Figure 3. (Note that the 82586 $\overline{RTS}$ is tied to the 82501 $\overline{TEN}$ input as shown in Figure 4.)

Data encoding and transmission begins with $\overline{TEN}$ going low. Since the first bit is a '1', the first transition on the transmit output TRMT is always negative. Transmission ends with the $\overline{TEN}$ going high. The last transition is always positive at TRMT and may occur at the center of the bit cell (last bit = 1) or at the boundary of the bit cell (last bit = 0). A one-bit delay is introduced by the 82501 between its TXD input and TRMT/$\overline{TRMT}$ output as shown in Figure 3. Following the last transition, the output $\overline{TRMT}$ is slowly brought to its high state so that zero differential voltage exists between TRMT and $\overline{TRMT}$. This will eliminate DC currents in the primary of the transceiver's coupling transformer. See Figure 4.

An internal watchdog timer is started at the beginning of the frame. The duration of the watchdog timer is 25 msec ±15%. If the transmission terminates (by deasserting the $\overline{TEN}$) before the timer expires, the timer is reset (and ready for the next transmission). If the timer expires before the transmission ends, the frame is aborted. This is accomplished by disabling the output driver for the TRMT/$\overline{TRMT}$ pair and deasserting $\overline{CRS}$. RXD and $\overline{RXC}$ are not affected. The watchdog timer is reset only when the $\overline{TEN}$ is deasserted.

The cable driver is a differential gate requiring external resistors or a current sink of 20 mA (on both terminals). In addition, high-voltage protection of 15 volts maximum for 1 second maximum is provided.

Receive Section

CABLE INTERFACE AND NOISE FILTER

The 82501 input circuits can be driven directly from the Ethernet transceiver cable receive pair. In this case the cable is terminated with a pair of 39-ohm resistors in series for proper impedance matching. The center tap of the termination is tied to an external voltage reference (source impedance of 18.5 ohms min.) to establish the required common mode voltage bias for the 82501 receive circuitry. See Figure 4.

The input circuits can also be driven with ECL voltage levels. In either case, the input common mode voltage must be in the range of $V_{CC}-1.0$ to $V_{CC}-2.5$ volts to allow for a wide driver supply variation at the transceiver. The input terminals have a 15-volt maximum protection and additional clamping of low-energy, high-voltage noise signals.

A noise filter is provided at the RCV/$\overline{RCV}$ input pair to prevent spurious signals from improperly triggering the receiver circuitry. The noise filter has the following characteristics:

A negative pulse which is narrower than 30 ns or is less than −150 mV in amplitude is rejected during idle.

At the beginning of a reception, the filter is activated by the first negative pulse which is more negative than −250 mV and is wider than 50 ns.

As soon as the first valid negative pulse is recognized by the noise filter, the $\overline{CRS}$ signal is asserted to inform the 82586 controller of the beginning of a transmission, and the $\overline{RXC}$ will be held low for 1.2 μsec maximum while the internal phase-locked-loop is acquiring lock.

The filter is deactivated if no negative transition occurs within 160 ns from the last positive transition.

Immediately after the end of a reception, the filter blocks all the signals for 5 μsec minimum, 7 μsec maximum. This dead time is required to block-off spurious transitions which may occur on the coaxial cable at the end of a transmission but are not filtered out by the transceiver.

MANCHESTER DECODER AND CLOCK RECOVERY

The filtered data enters the clock recovery and decoder circuits. An analog phase-locked-loop (PLL) technique is used to extract the received clock from the data, beginning from the third negative transition of the incoming data. The PLL will acquire lock within the first 12 bit times, as seen from the RCV/$\overline{RCV}$ inputs. During that period of time, the $\overline{RXC}$ is held low. Bit cell timing distortion which can be tolerated in the incoming signal is ±15 nsec for the preamble and ±20 nsec for data. The voltage-controlled oscillator (VCO) of the PLL corrects its frequency to match the incoming signal transitions.

Its VCO cycle time stays within 5% of the RXD bit cell time regardless of the time distortion allowed at the RCV/$\overline{RCV}$ input. The RCV/$\overline{RCV}$ input is decoded from Manchester to NRZ and transferred synchronously with the receive clock to the 82586 controller.

At the end of a frame, the receive clock is used to detect the absence of RCV/$\overline{RCV}$ transitions and report it to the 82586 by deasserting $\overline{CRS}$ while $\overline{RXD}$ is held high.

Collision-Presence Section

The CLSN/$\overline{CLSN}$ input signal is a 10 MHz ±15% square wave generated by the transceiver whenever two or more data frames are superimposed on the coaxial cable. The maximum asymmetry in the CLSN/$\overline{CLSN}$ signal is 60/40% for low-to-high or high-to-low levels. This signal is filtered for noise rejection in the same manner as RCV/$\overline{RCV}$. The noise filter rejects signals which are less negative than −150 mV and narrower than 15 ns during idle. It turns on at the first negative pulse which is more negative than −250 mV and wider than 30 ns. After the initial turn-on, the filter remains active indicating that a valid collision signal is present, as long as the negative CLSN/$\overline{CLSN}$ signal pulses are more negative than −250 mV. The filter returns to the "off" state if the signal becomes less negative than −150 mV, or if no negative transition occurs within 160 ns from the last positive transition. Immediately after turn-off, the collision filter is ready to be reactivated.

The common mode voltage and external termination are identical to the RCV/$\overline{RCV}$ input. (See Figure 4.) The CLSN/$\overline{CLSN}$ input also has a 15-volt maximum protection and additional clamping against low-energy, high-voltage noise signals.

A valid collision-presence signal will assert the 82501 $\overline{CDT}$ output which can be directly tied to the $\overline{CDT}$ input of the 82586 controller.

During the time that valid collision-presence transitions are present on the CLSN/$\overline{CLSN}$ input, invalid data transitions will be present on the receive data pair due to the superposition of signals from two or more stations transmitting simultaneously. It is possible for RCV/$\overline{RCV}$ to lose transitions for a few bit times due to perfect cancellation of the signals. In any case, the invalid data will not cause any discontinuity of RXC.

When a valid collision-presence signal is present the $\overline{CRS}$ signal is asserted (along with $\overline{CDT}$). However, if this collision-presence signal arrives within 6.0 ±1.0 μs from the time $\overline{CRS}$ was deasserted, only $\overline{CDT}$ is generated.

Internal Loopback

When asserted, $\overline{LPBK}$ causes the 82501 to route serial data from its TXD input, through its transmit logic (retiming and Manchester encoding), returning it through the receive logic (Manchester decoding and receive clock generation) to RXD output. The internal routing prevents the data from passing through the output drivers and onto the transmit output pair, TRMT/$\overline{TRMT}$. When in loopback mode, all of the transmit and receive circuits, including the noise filter, are tested except for the transceiver cable output driver and input receivers. Also, at the end of each frame transmitted in loopback mode, the 82501 generates a 1-μsec $\overline{CDT}$ signal within 1 μsec after the end of the frame. Thus, the collision circuits, including the noise filter, are also tested in loopback mode. The watchdog timer remains enabled in loopback mode, terminating test frames that exceed its time-out period.

In the normal mode ($\overline{LPBK}$ not asserted), the 82501 operates as a full duplex device, being able to transmit and receive simultaneously. This is similar to the external loopback mode of the 82586. Combining the internal and external loopback modes of the 82586 and the internal loopback and normal modes of the 82501, incremental testing of an 82586/82501-based interface can be performed under program control for systematic fault detection and fault isolation.

Interface Example

The 82501 is designed to work directly with the 82586 controller in Ethernet as well as non-Ethernet 10 Mbps LAN applications. The control and data signals connect directly between the two devices without the need for additional external logic. The complete 82586/82501/Ethernet Transceiver cable interface is shown in FIGURE 4. The 82501 provides the driver and receivers needed to directly connect to the transceiver cable, requiring only terminating resistors on each input signal pair.

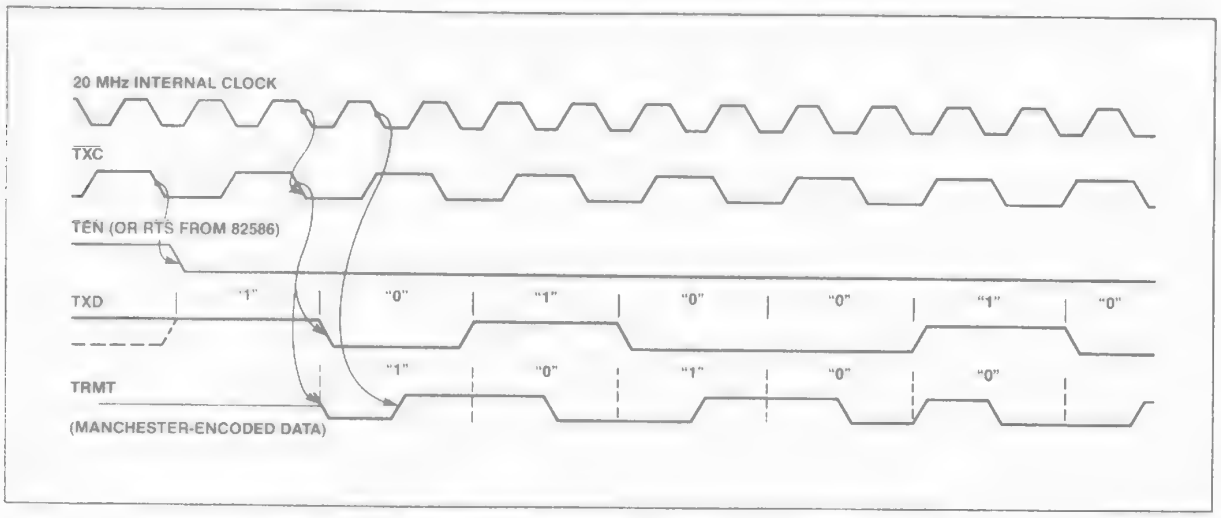

Figure 3. Start of Transmission and Manchester Encoding

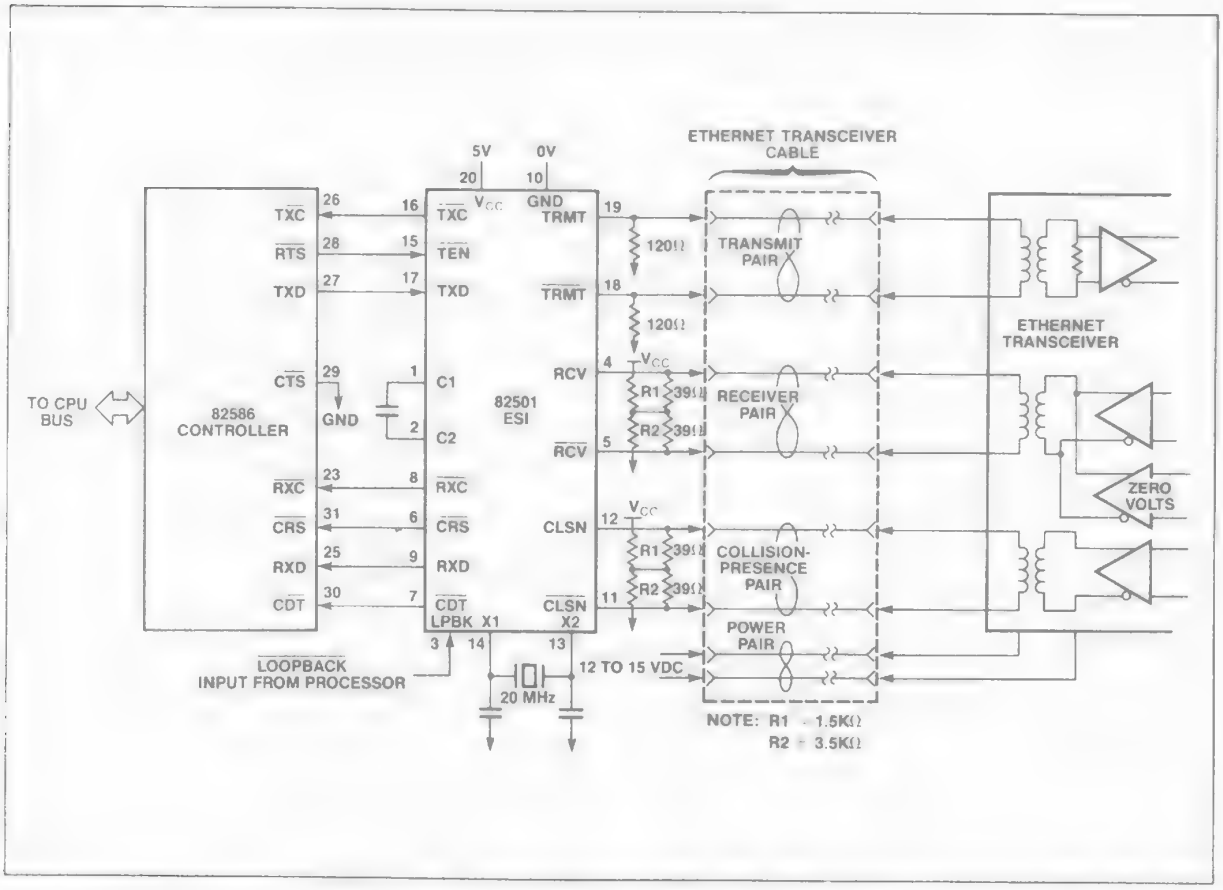

Figure 4. 82586/82501/Transceiver Cable Interface

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D.C. CHARACTERISTICS (T_A = 0–70°C, V_{CC} = 5V ±10%)

Symbol	Parameter	Min.	Max.	Units	Conditions
V_{IL}	Input Low Voltage (TTL)	−0.5	+0.8	V	
V_{IH}	Input High Voltage (TTL)	2.0	V_{CC} + 0.5	V	
V_{IDF}	Input Differential Voltage (Differential)	±250	±1000	mV	
V_{CM}	Input Common Mode Voltage (Differential)	V_{CC} − 2.5	V_{CC} − 1.0	V	
V_{OL}	Output Low Voltage TTL or MOS		0.45	V	I_{OL} = 8 mA
V_{OCM}	Common Mode Output	1.0	4.5	V	R_L = 78 Ohms Differential Termination and 120Ω pulldown
V_{OH}	Output High Voltage				
	TTL	2.4		V	I_{OH} = −1.0 mA
	MOS	3.9		V	I_{OH} = −400 μA
V_{ODF}	Differential Output Swing	0.55	1.2	V	R_L = 78 Ohms Differential Termination and 120Ω pulldown
I_{LI}	Input Leakage Current		±200	μA	$0 < V_{IN} < V_{CC}$
C_{IN}	Input Capacitance		10	pF	f = 1 MHz
C_{OUT}	Output Capacitance		20	pF	f = 1 MHz
I_{CC}			200	mA	

A.C. CHARACTERISTICS

A.C. Measurement Conditions

I) T_A = 0° to 70°C, V_{CC} = 5V ± 10%

II) The AC measurements are done at the following voltage levels for the various kinds of inputs and outputs

a) TTL inputs and oututs: 0.8V and 2.0V
The input voltage swing is 0.4 to 2.4V at least with 3–10 ns rise and fall times.

b) MOS outputs: The rise and fall times are measured between 0.6V and 3.6V points. The high time is measured between 3.6V points and the low time is measured between 0.6V points.

c) Differential inputs and outputs:
The 50% points of the total swing are used for delay measurements. The rise and fall times of outputs are measured at the 20 to 80% points. The differential voltage swing at the inputs is at least ±250 mV with rise and fall times of 3–15 ns measured at ±.2 volts.

III) The AC loads for the various kind of outputs are as follows:

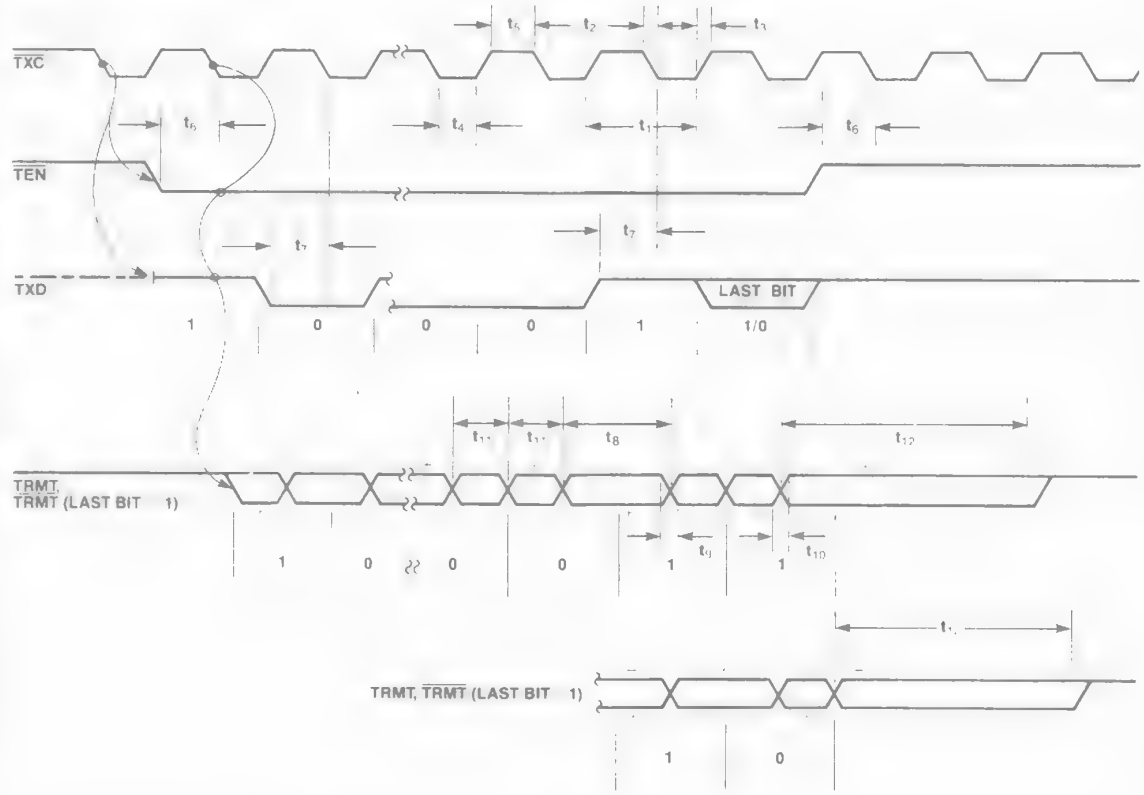
a) TTL and MOS: A 20-pF Capacitor to GND

b) Differential: A 10-pF Capacitor from each terminal to GND and a termination load resistor of 78 ohms in parallel with a 27 microhenries inductor between the two terminals.

TRANSMIT TIMING

Symbol	Parameter	Min.	Max.	Unit
t_1	$\overline{TXC}$ Cycle Time	99.99	100.01	ns
t_2	$\overline{TXC}$ Fall Time		5	ns
t_3	$\overline{TXC}$ Rise Time		5	ns
t_4	$\overline{TXC}$ Low Time	40		ns
t_5	$\overline{TXC}$ High Time	40		ns
t_6	Transmit Enable/Disable to $\overline{TXC}$ Low	50		ns
t_7	TXD Stable to $\overline{TXC}$ Low	50		ns
t_8	Bit Cell Center to Bit Cell Center of Transmit Pair Data	99.5	100.5	ns
t_9	Transmit Pair Data Fall Time	1.0	5.0	ns
t_{10}	Transmit Pair Data Rise Time	1.0	5.0	ns
t_{11}	Bit Cell Center to Bit Cell Boundary of Transmit Pair Data	49.5	50.5	ns
t_{12}	$\overline{TRMT}$ starts approaching its high level from Last Positive Transition of Transmit Pair Data during idle.	160		ns

TRANSMIT TIMING



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RECEIVE TIMING

Symbol	Parameter	Min.	Max.	Unit
t_{13}	Receive Pair Signal Pulse Width (at −.25V differential signal) of First Negative Pulse for a) Signal Rejection by Noise Filter, b) Noise Filter Turn-on in order to Begin Reception	 50	30	ns ns
t_{14}	Duration which the $\overline{RXC}$ is held at low state		1200	ns
t_{15}	Receive Pair Signal Rise/Fall Time at ±.2 volt		15	ns
t_{16}	Receive Pair Signal Bit Cell Center to Bit Cell Center allowing for timing distortion In preamble In data	 70 60	 130 140	 ns ns
t_{17}	Receive Pair Signal Bit Cell Center to Bit Cell Boundary allowing for timing distortion In preamble In data	 20 10	 80 90	 ns ns
t_{18}	Receive Idle Time Before the Next Reception can Begin (as measured from the deassertion of $\overline{CRS}$)		[illegible]	μs
t_{19}	Receive Pair Signal Return to Zero Level from Last valid Positive Transition	0.20	5	μs
t_{20}	$\overline{CRS}$ Assertion delay from the First received valid Negative Transition of Receive Pair Signal		100	ns

Symbol	Parameter	Min.	Max.	Unit
t_{21}	$\overline{CRS}$ Deassertion delay from the Last valid positive transition received (when no Collision-Presence signal exists on the transceiver cable)		300*	ns
t_{22}	$\overline{RXC}$ stopped from the first valid negative transition of RCV/$\overline{RCV}$		150	ns
t_{23}	$\overline{RXC}$ delay from RCV/$\overline{RCV}$ Bit Cell Center		100	ns
t_{24}	$\overline{RXC}$ Jitter		±5.0	ns
t_{25}	$\overline{RXC}$ Rise/Fall time		5	ns
t_{26}	$\overline{RXC}$ High/Low time	40		ns
t_{27}	Receive Data Stable before the Negative Edge of $\overline{RXC}$	30		ns
t_{28}	Receive Data Held valid past the Negative Edge of $\overline{RXC}$	30		ns
t_{29}	Carrier Sense deasserted before the Negative Edge of $\overline{RXC}$	10	30	ns
t_{30}	Receive data Rise/Fall time		10	ns
t_{31}	From the time $\overline{CRS}$ is deasserted until the time it can be asserted again	5	7	μs

*NOTE:
$\overline{CRS}$ is deasserted synchronously with the $\overline{RXC}$. This condition is not specified in the Ethernet specification.

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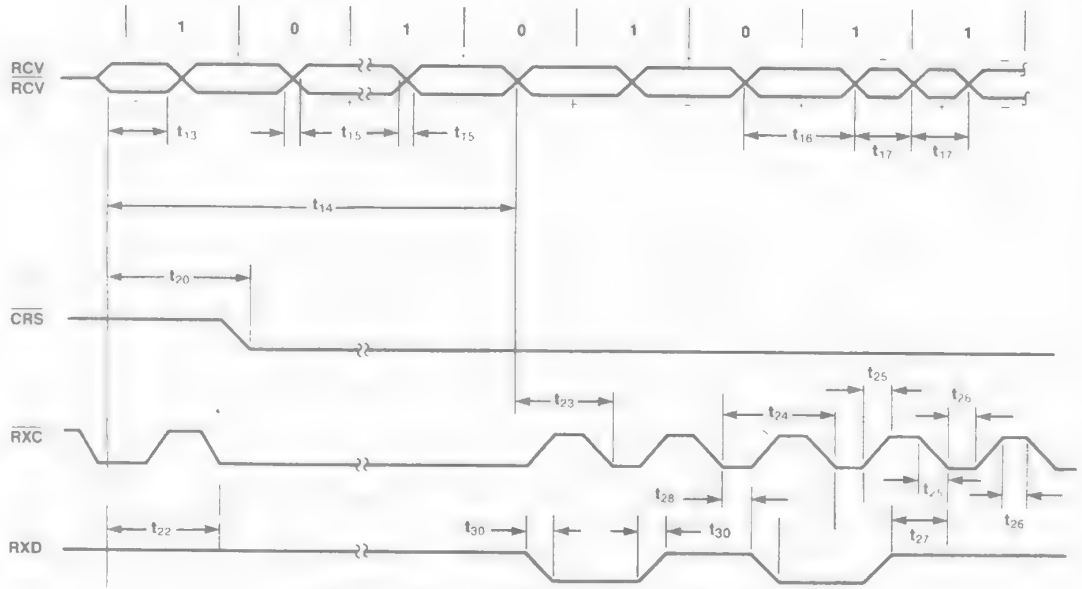
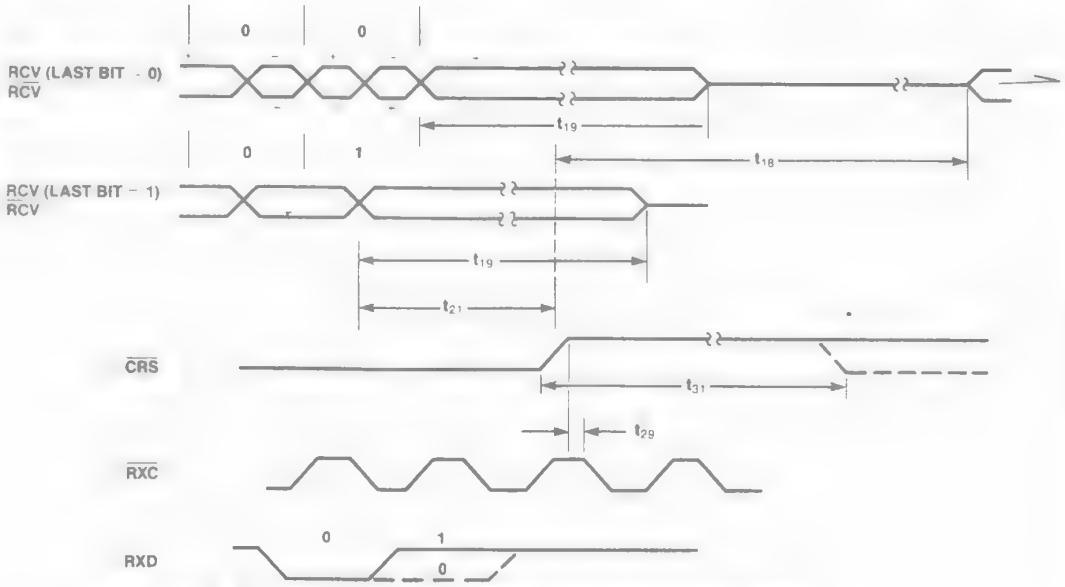
RECEIVE TIMING: START OF FRAME



*THIS CLOCK PULSE MAY NOT BE A VALID CLOCK PULSE.

RECEIVE TIMING: END OF FRAME



*NOTE. CRS CAN BE TRIGGERED ON AGAIN BY THE COLLISION-PRESENCE SIGNAL

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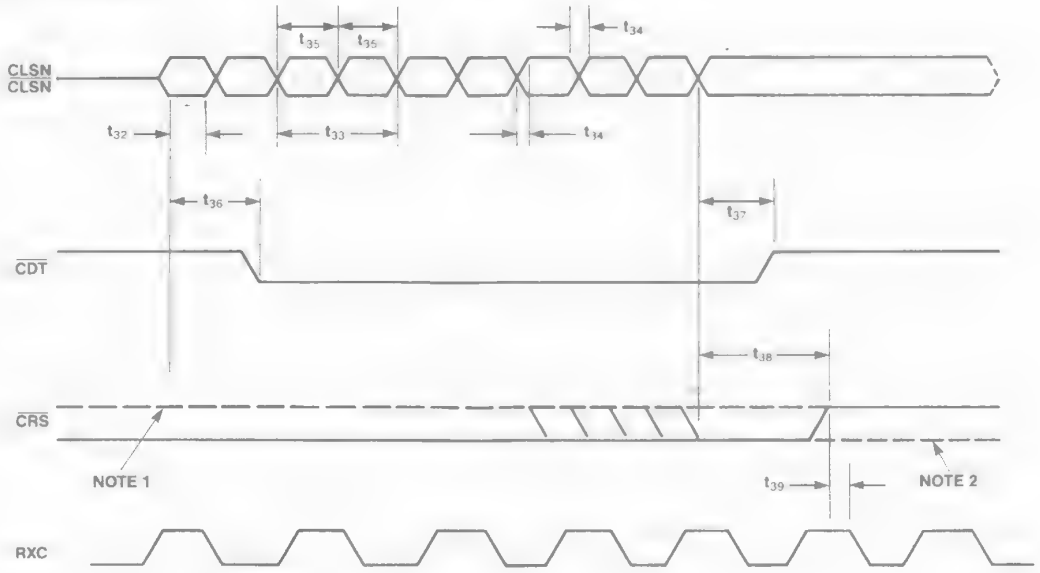
COLLISION TIMING

Symbol	Parameter	Min.	Max.	Unit
t_{32}	CLSN/$\overline{CLSN}$ Signal Pulse Width (at −.25V differential signal) of First Negative Pulse for Noise Filter Turn-on	30		ns
t_{33}	CLSN/$\overline{CLSN}$ Cycle Time	86	118	ns
t_{34}	CLSN/$\overline{CLSN}$ Rise/Fall Time at ±.2 volts		15	ns
t_{35}	CLSN/$\overline{CLSN}$ Transition Time	35	70	ns
t_{36}	$\overline{CDT}$ Assertion from the First Valid Negative Edge of Collision Pair Signal		75	ns
t_{37}	$\overline{CDT}$ Deassertion from the Last Positive Edge of CLSN/$\overline{CLSN}$ Signal		200	ns
t_{38}	$\overline{CRS}$ Deassertion from the Last Positive Edge of CLSN/$\overline{CLSN}$ signal (If no post-collision signal remains on the receive pair.)		350	ns
t_{39}	$\overline{CRS}$ stable before the negative edge of $\overline{RXC}$ at deassertation	10	30	ns

COLLISION TIMING



NOTES:
1. CRS WILL BE DEASSERTED FOR A PERIOD UP TO 7 μSEC MAXIMUM WHEN RCV/$\overline{RCV}$ OR CLSN/$\overline{CLSN}$ TERMINATES, WHICHEVER OCCURS LATER.
2. $\overline{CRS}$ WILL REMAIN ASSERTED AFTER THE CLSN/$\overline{CLSN}$ SIGNAL TERMINATES IF RCV/$\overline{RCV}$ SIGNALS CONTINUE

LOOPBACK TIMING

Symbol	Parameter	Min.	Max.	Unit
t_{40}	$\overline{LPBK}$ asserted before the first attempted transmission	500		ns
t_{41}	Simulated collision test delay from the end of each attempted transmisssion	.5	1.0	μs
t_{42}	Simulated collision test duration	.5	1.0	μs
t_{43}	$\overline{LPBK}$ deasserted after the last attempted transmission	5		μs

NOTE:
In Loopback mode, $\overline{RXC}$, $\overline{RXD}$ and $\overline{CRS}$ function in the same manner as a normal Receive.

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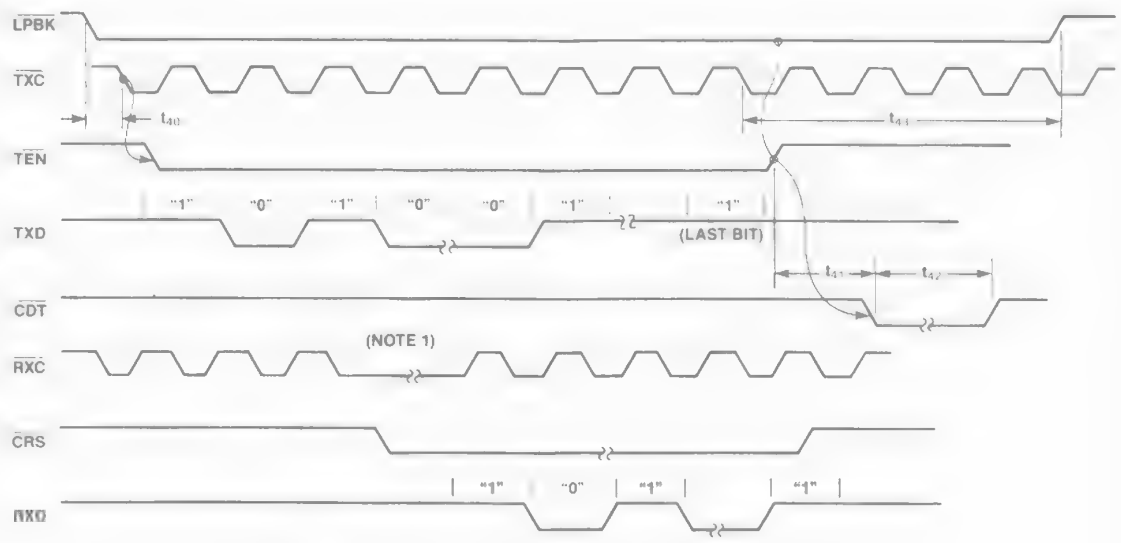
LOOPBACK TIMING



NOTE:
1. DURING LOOPBACK, THE 82501 RECEIVE CIRCUITRY USES 12 BIT TIMES WHILE THE PLL LOCKS ON THE DATA. AS A RESULT, THE FIRST 12 BITS ARE LOST.

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TECHNICAL REFERENCES

6.1 The Ethernet Specification Version 1.0, August, 1980 Digital Equipment Corporation, Intel, Xerox
6.2 ISO "Reference Model for Open Systems Interconnection Architecture", ISO/TC97/SC16 N309
6.3 Intel "Local Network Architecture Proposed For Work Stations" August, 1981 Article Reprint 186
6.4 Intel iNA 950-1 Local Area Network Software Data Sheet
6.5 Intel iSBC 550 Ethernet MultiBus Controller Board Set Data Sheet
6.6 Intel "System Level Functions Ehance Controller IC", October 6, 1982 Electronics

ADVANCE INFORMATION

82586
LOCAL COMMUNICATIONS CONTROLLER

- **Fully Implements the Ethernet* and Proposed IEEE 802 Specifications**
- **User Configurable for Non-Ethernet Applications**
  - **—From 0 to 6 Bytes of Address Generation/Checking**
  - **—16- or 32-Bit CRC Generation/Checking**
  - **—Optional Priority Function**
  - **—Variable Preamble Length**
  - **—Serial Transmission from 100 Kbps to 10 Mbps**
  - **—8- or 16-Bit Data Bus**
- **4 On-Chip DMA Channels for Efficient, High-Speed Transfer of Data, Status and Commands**
- **Complete Set of Diagnostics for Reliable Network Operation**
- **Fully Implements the CSMA/CD Access Method Including Retries and Random Backoff (Wait) Time**
- **Two Methods of Frame Delimiting: Ethernet and HDLC Flags/Bit Stuffing**
- **Independent 8-MHz System Clock Input**

Designed as an intelligent peripheral, the 82586 manages the entire process of transmitting and receiving frames, thereby relieving the host processor of the tasks of managing the communications peripheral. The major functions performed by the 82586 include:

—direct transfer of frames to and from external memory using four on-chip DMA channels.
—executes commands from lists residing in external shared memory.
—automatically reports the status of both transmitted and received frames, including error conditions.
—fully integrates the CSMA/CD access method including automatic retries after collisions and random backoff (wait-time) generation.
—diagnostic commands to identify and isolate faults.

In order to take full advantage of the LAN concept and CSMA/CD access method, the 82586 architecture is also configurable under program control. This allows the 82586 to be "customized" for other applications requiring high-speed serial transmission including serial backplanes (serial peripheral interconnection) and low-cost, short-distance LANs.

*Ethernet is a trademark of Xerox Corporation.

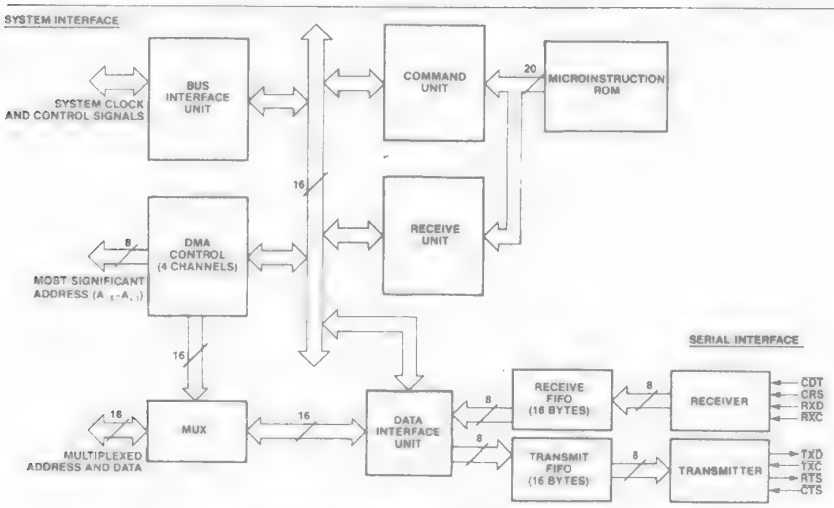
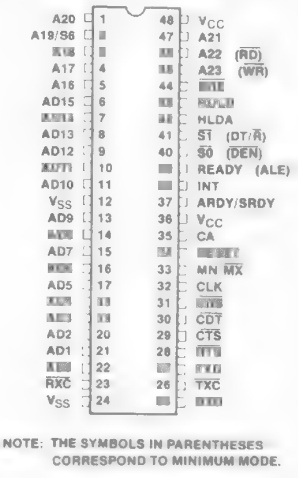


Figure 1. 82586 Functional Block Diagram



NOTE: THE SYMBOLS IN PARENTHESES CORRESPOND TO MINIMUM MODE.

Figure 2. 82586 Pinout

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Controlling the 82586

From the user's point of view, the 82586 consists of two independent, though communicating units: the Command Unit (CU) and the Receive Unit (RU) as shown in Figure 3. The CU executes commands given by the host CPU and manages frame transmissions. The RU handles all activities related to frame reception such as buffer management, frame and address recognition, and CRC checking. The two units are controlled and monitored by the host CPU via a shared memory structure called the System Control Block (SCB). All logical communication between the CPU and 82586 takes place through the SCB. The two other memory structures used by the 82586 are the Command Block List (CBL) and Receive Frame Area (RFA). These are used to hold the list of commands to be executed by the 82586 and hold all received frames, respectively. Pointers to the CBL and RFA are in the SCB, along with status registers and counters for certain tallies maintained by the 82586, and control commands for the 82586. The only direct control lines between the CPU and the 82586 are the interrupt to the CPU and Channel Attention to the 82586.

82586 Memory Structures

The three primary memory structures used by the host CPU and the 82586 to pass control, status and data are the System Control Block (SCB), Command Block List (CBL) and the Receive Frame Area (RFA), Figure 4.

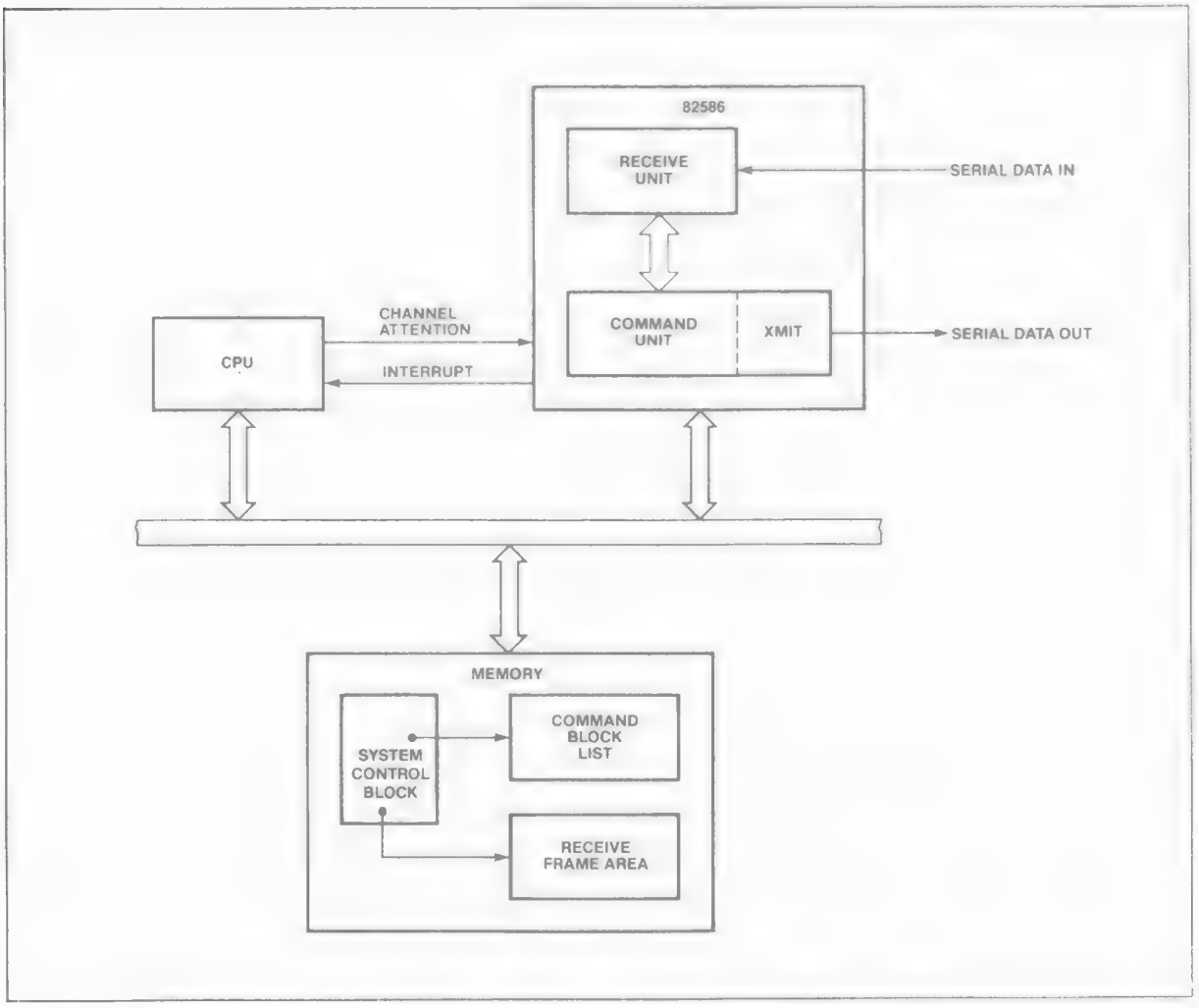

Figure 3. System Overview

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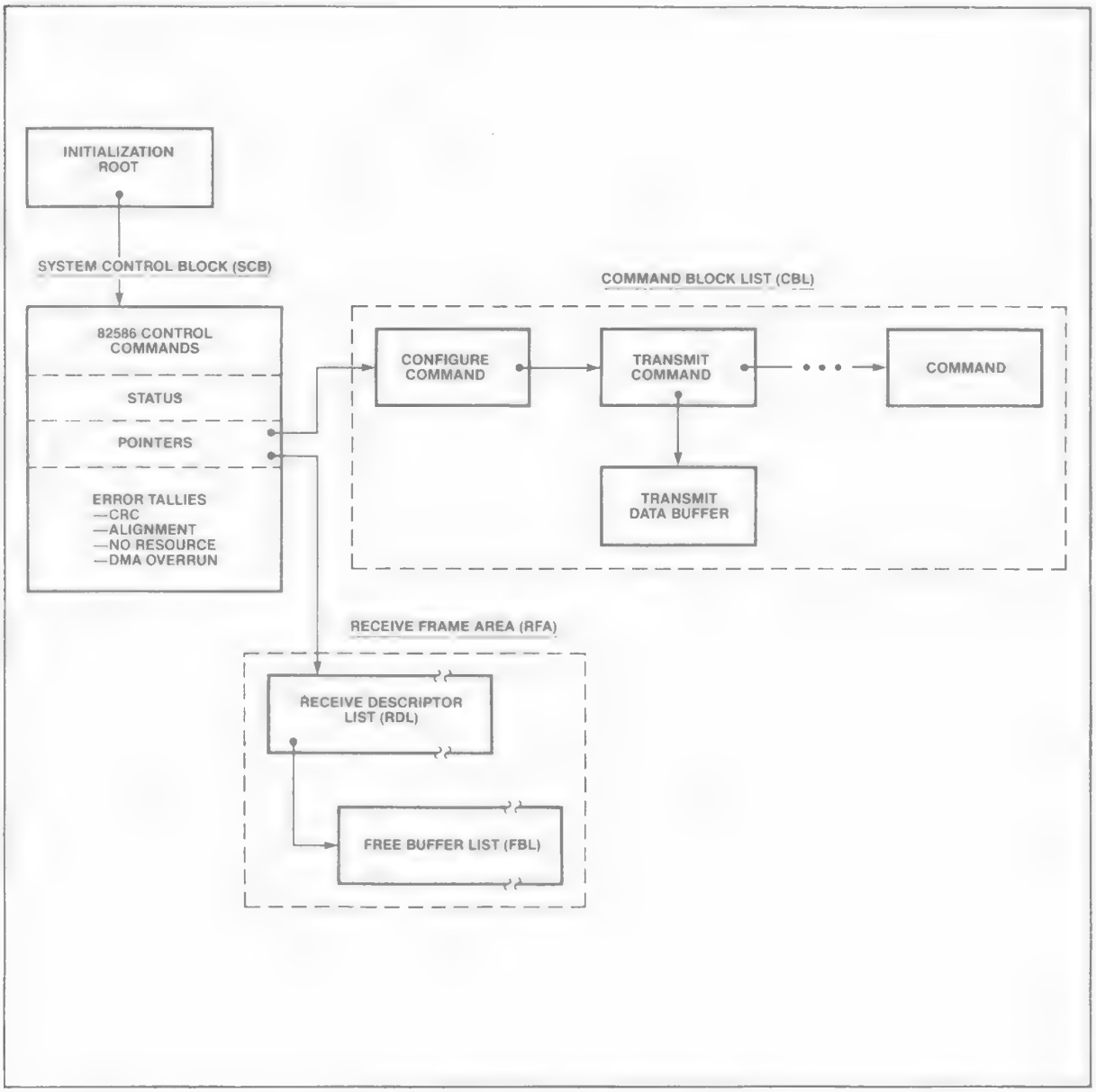

Figure 4. 82586 Memory Structures

Upon initialization, the 82586 obtains the address of its System Control Block through the Initialization Root which begins at location 0FFFFF6H. The SCB contains control commands, status register, pointers to the Command Block List (CBL) and Receive Frame Area (RFA), and tallies for CRC, Alignment, DMA Overrun and No Resource errors. Through the SCB, the 82586 is able to provide status and error counts for the host CPU, execute "programs" contained in the Command Block List (CBL) and receive incoming frames in the Receive Frame Area (RFA).

Both the Command Block List and the Receive Frame Area are first configured by the host CPU and then passed to the 82586 via the SCB. As commands are executed by the 82586, it returns status information back to the CPU, which may, in turn, update the CBL with additional commands. As frames are received by the 82586 and stored in the RFA, the 82586 will return the appropriate status to the CPU. The CPU retrieves the received frames from the RFA and returns free buffers to the Receive Descriptor and Free Buffer lists.

The 82586 has a 22-bit memory address range in minimum mode and 24-bit memory address range in maximum mode. All memory structures, the System Control Block, commands in the Command Block List, Receive Descriptor List, and all buffer descriptors (see Figure 6), must reside within one 64K-byte memory segment. The Data Buffers can be located anywhere in the memory space.

Transmitting Frames

The 82586 executes commands from the Command Block List in external memory. These commands are fetched and executed in parallel with the host CPU's operation, thereby significantly improving system performance potential. The general format for such commands is

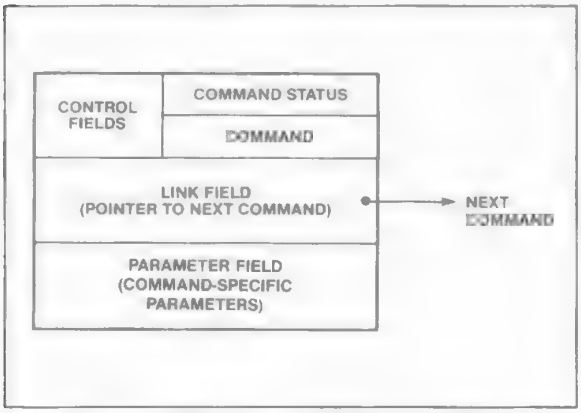

Figure 5. Action Command Format

Via the Link Field, commands can be linked together to form a list of commands for execution by the 82586.

One such command is the Transmit command. A single Transmit command contains, as part of the command-specific parameters, the destination address and type field for the transmitted frame along with a pointer to a buffer area in memory containing the data portion of the frame. The data field is contained in a memory data structure consisting of a Buffer Descriptor (BD) and Data Buffer (or a linked list of buffer descriptors and buffers) as seen in Figure 6. The BD contains a Link Field which points to the next BD on the list and a 24-bit address pointing to the Data Buffer itself. The length of the Data Buffer is specified by the Actual Count field of the BD.

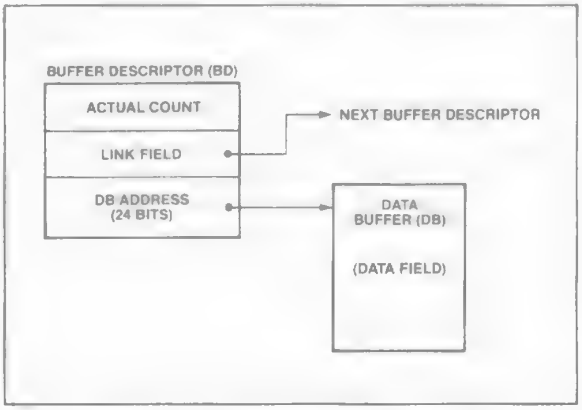

Figure 6. Transmit Data Buffer

Using the BDs and Data Buffers, multiple Data Buffers can be "chained" together. Thus, a frame with a long Data Field can be transmitted using multiple (shorter) Data Buffers chained together. This chaining technique allows the system designer to develop efficient buffer management policies.

When transmitting a frame as shown below:

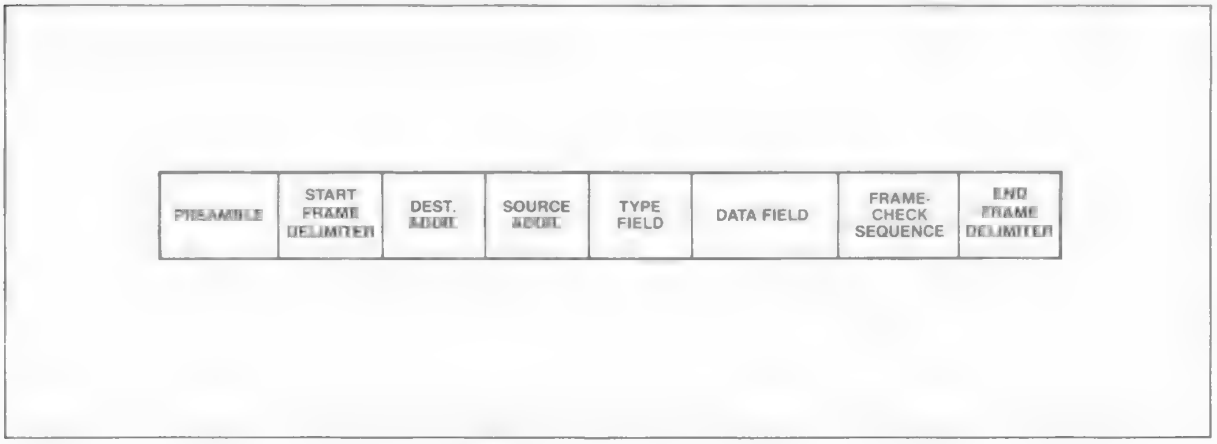

Figure 7. Frame Format

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The 82586 automatically generates the preamble (alternating 1s and 0s) and start frame delimiter, fetches the destination address and type field from the Transmit command, inserts its unique address as the source address, fetches the data field from buffers pointed to by the Transmit command, and computes and appends the CRC at the end of the frame.

The 82586 can be configured to generate either the Ethernet or HDLC start and end frame delimiters. In the Ethernet mode, the start frame delimiter is two consecutive 1 bits and the end frame delimiter indicated by the lack of a signal after transmitting the last bit of the frame-check sequence field. When in the HDLC mode, the 82586 will generate the 01111110 "flag" for the start and end frame delimiters and perform the standard "bit stuffing/stripping." In addition, the 82586 will optionally pad frames that are shorter than the specified minimum frame length by appending the appropriate number of flags to the end of the frame.

In the event of a collision (or collisions), the 82586 manages the entire jam, random wait and retry process, reinitializing DMA pointers without CPU intervention. Multiple frames can be sent by linking the appropriate number of Transmit commands together. This is particularly useful when transmitting a message that is larger than the maximum frame size (1518 bytes for Ethernet).

Receiving Frames

In order to minimize CPU overhead, the 82586 is designed to receive frames without CPU supervision. The host CPU first sets aside an adequate amount of receive buffer space and then enables the 82586's Receive Unit. Once enabled, the 82586 "watches" for any of its frames which it automatically stores in the Receive Frame Area (RFA). The RFA consists of a Receive Descriptor List (RDL) and a list of free buffers called the Free Buffer List (FBL) as shown in Figure 8. The individual Receive Frame Descriptors that make up the RDL are used by the 82586 to store the destination and source address, type field and status of each frame that is received. (Figure 9.)

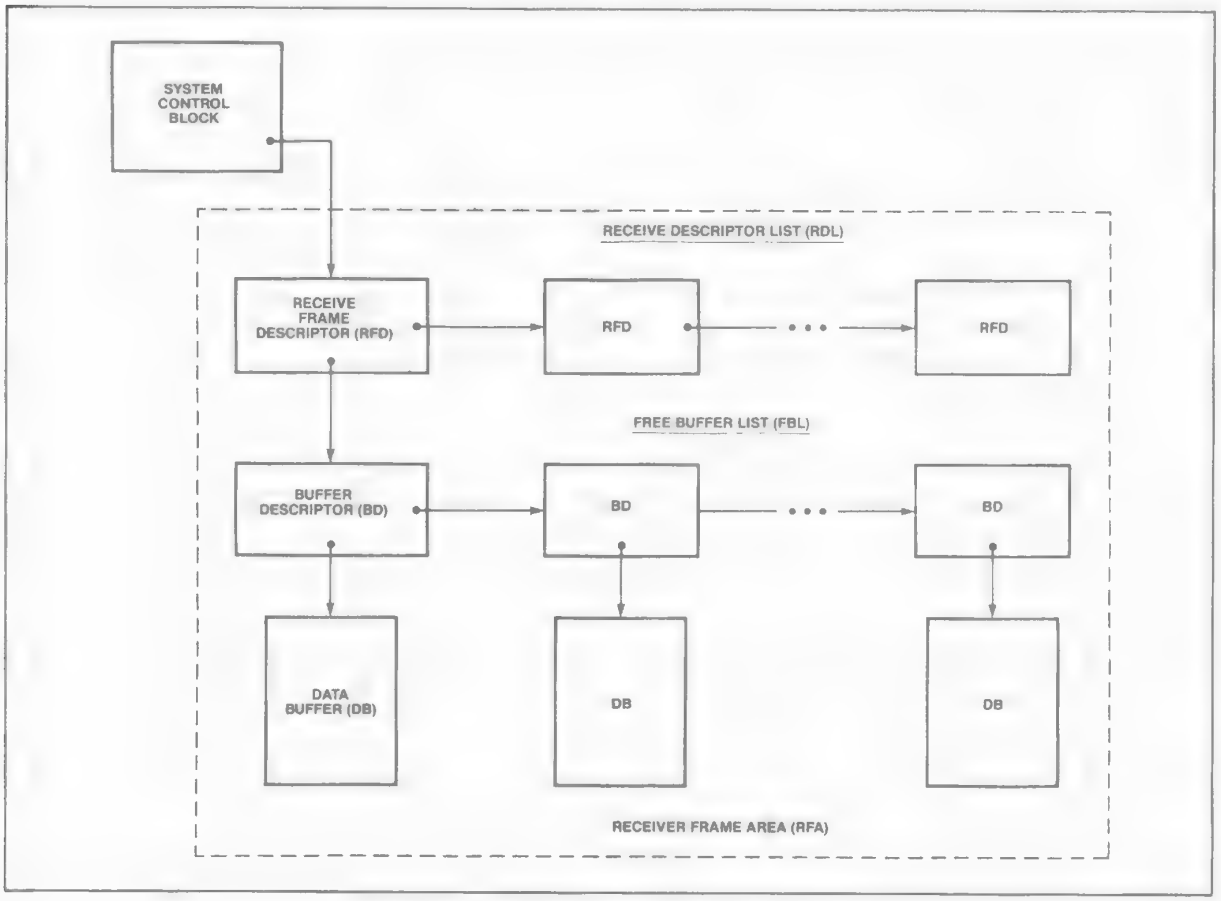

Figure 8. Receive Frame Area Diagram

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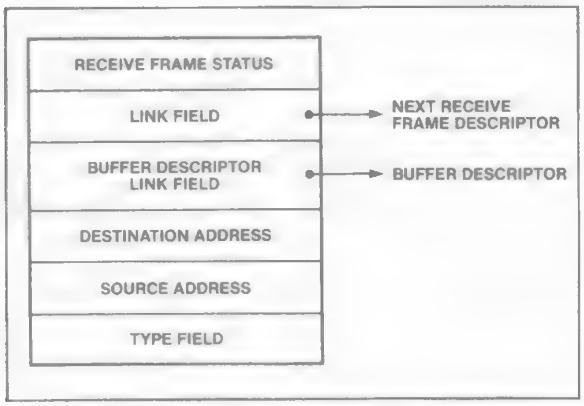

Figure 9. Receive Frame Descriptor

The 82586, once enabled, checks each passing frame for an address match. The 82586 will recognize its own unique address, one or more multicast addresses or the broadcast address.

If a match occurs, it stores the destination and source address and type field in the next available RFD. It then begins filling the next free Data Buffer on the FBL (which is pointed to by the current RFD) with the data portion of the incoming frame. As one DB is filled, the 82586 automatically fetches the next DB on the FBL until the entire frame is received. This buffer chaining technique is particularly memory efficient because it allows the system designer to set aside buffers that fit a frame size that may be much shorter than the maximum allowable frame. Without buffer chaining, all receive data buffers would have to be as long as the maximum allowable frame.

Once the entire frame is received without error, the 82586 performs the following housekeeping tasks:

—Updates the Actual Count field of the last Buffer Descriptor used to hold the frame just received with the number of bytes stored in its associated Data Buffer.
—Fetches the address of the next free Receive Frame Descriptor.
—Writes the address of the next free Buffer Descriptor into the next free Receive Frame Descriptor.
—Posts a "Frame Received" interrupt status bit in the SCB.
—Interrupts the CPU.

In the event of a frame error, such as a CRC error, the 82586 automatically reinitializes its DMA pointers and reclaims any data buffers containing the bad frame. As long as Receive Frame Descriptors and data buffers are available, the 82856 will continue to receive frames without further CPU help.

82586 Action Commands

The 82586 executes a "program" that is made up of action commands in the Command Block List. As shown in Figure 5, each command contains the command field, status and control fields, link to the next action command in the CBL, and any command-specific parameters. The 82586 has a repertoire of 8 commands.

NOP
Set Up Individual Address
Configure
Set Up Multicast Address
Transmit
TDR
Diagnose
Dump

NOP:
This command results in no action by the 82586 other than the normal command processing such as fetching the command and decoding the command field.

Individual Address Set Up:
This command is used to load the 82586's unique address. The unique address is contained in the parameter field of the command.

Configure:
The Configure command is used to load the 82586 with its operating parameters. Upon reset, the 82586 initializes to the Ethernet-based parameters. If the user wishes to use any other values, the Configure command is used.

Multicast Address Set Up:
This command allows the programmer to set up one or more multicast addresses into the 82586. The multicast addresses to be set up are located in the parameter field of the command.

Transmit:
One Transmit command is used to send a single frame. If more than one frame is to be sent, the host CPU can link multiple Transmit commands together. The destination address, type field and pointer to buffers containing the data field are contained in the parameter field of the Transmit command.

TDR:
This command performs the Time Domain Reflectometry test on the coaxial cable. The TDR command is used to detect and locate cable faults caused by either short or open circuits on the coaxial cable.

Diagnose:
The Diagnose command puts the 82586 through a self-test procedure and reports on the success or failure of the internal test.

Dump:
This command causes the 82586 to dump its internal registers into memory. The registers included are those loaded by the Configure and Address Set-Up commands, plus status and other internal working registers.

PROGRAMMABLE NETWORK PARAMETERS AND DIAGNOSTICS

Network Parameters

The Ethernet specification represents a complete description of the physical and data link layers of a local-area network. As such, items such as address and preamble length, maximum distance between two stations, and frame-check sequence length are fixed to assure that stations connecting to the network are compatible. Through the Configure command, the 82586 can also be tailored to achieve maximum efficiency in other network configurations. The following parameters can be specified in the Configure command:

PARAMETER	LENGTH
Source/Destination Address	0 to 6 bytes
CRC	16 or 32 bits
Preamble Length	16, 32, 64, or 128 bits
Frame Delimiter	Ethernet or HDLC (Flags and bit stuffing)
Slot Time	11 bits to specify number of transmit clock times

The Slot time is a period slightly longer than the maximum round-trip delay time through the network, i.e., the round-trip delay between the two most distant stations. The Slot time is used in the CSMA/CD Backoff calculation where the random time is defined in increments of the Slot Time. Shorter networks, such as a serial backplane within a cabinet would have a very short Slot Time compared to a 2500-meter Ethernet Network, for example.

Priority can also be assigned via a field in the Configure command. This field specifies the amount of time the particular 82586 must wait after the cable has been quiet before attempting to transmit its frame. By assigning lower-priority stations a longer wait time, the high-priority (shorter wait-time) stations will have better access to the cable during peak busy periods.

Diagnostics

In addition to specifying network parameters, the Configure command is also used to call up a powerful set of diagnostic functions through individual fields within the command.

Save Bad Frame:
Under normal operation, the 82586 automatically discards frames with errors, such as a CRC error. Frames can be saved for later examination by requesting it through this field.

Address/Type Field Location:
This field informs the 82586 that the destination and source addresses and type field are the first entries in the Transmit Data Buffer rather than in the parameter field of the Transmit command (destination address and type field) and Individual Address register of the 82586 (source address).

Loopback:
Two Loopback modes are available on the 82586. The Internal Loopback moves the transmitted frame from memory into the 82586 FIFO, through the bit transmitter, back into the bit receiver and back to memory without going through the external serial drivers and receivers of the 82586. Note that the data moves at one-fourth the normal bit rate when the 82586 is in Internal Loopback.

External Loopback is identical to the Internal Loopback except that the frame does move out through the serial drivers and back in through receivers of the 82586 at the normal bit rate. This allows external components, such as the 82501 ESI chip and Ethernet transceivers, to be tested independently of the coaxial cable or remote station.

Promiscuous Receive:
The 82586 can be made to receive all good frames, regardless of address, using this field. This is useful as a monitor or diagnostic mode for a station.

Broadcast Disable:
This field is used to disable the reception of all broadcast messages by the 82586.

Minimum Frame Length:
The 82586 automatically rejects received frames which are shorter than the minimum frame length as specified in this field. This 9-bit field allows the minimum frame length to range from 1 to 511 bytes. (For Ethernet the minimum frame is 64 bytes.)

No CRC Insertion:
This field disables the automatic CRC insertion and terminates the frame after last byte of the data field is transmitted. Using this option, frames with the wrong CRC can be generated in order to test a receiving station's CRC checking circuitry.

As an aid to monitoring the operation of the network and tracking its "vital signs," the 82586 also reports the following conditions after each received and transmitted frame.

RECEIVED FRAME
—No errors
—Short Frame (less than minimum frame length)
—DMA Overrun; FIFO overflow before DMA service
—CRC error
—Alignment error
—No resources (buffers) to store frame

TRANSMITTED FRAME
—Frame transmitted
—Number of collisions encountered
—Transmission aborted, too many collisions
—DMA underrun; FIFO empty before DMA service
—Channel busy; 82586 deferred before frame transmission
—CTS (Clear To Send) lost
—CRS (Carrier Sense) lost
—Collision Test Status (Heartbeat Test)

System Interface

The 82586 operates as a bus master. Through its HOLD/HLDA signals, it is able to request bus cycles, transfer data and release the bus. Two internal 16-byte FIFOs are used to buffer data to and from the system bus through the four DMA channels on the 82586. Therefore, once the DMA request is granted, the 82586 is able to transfer multiple bytes of data (to fill or empty the FIFO) with each DMA request.

The 82586 system interface is a standard multiplexed bus that can be used with any of the popular 8- and 16-bit microprocessors. It is optimized for minimum-interface support logic when used with the iAPX 186 (Figure 10). When combined with the 82501 ESI chip, the Ethernet interface is complete from the CPU to the transceiver cable.

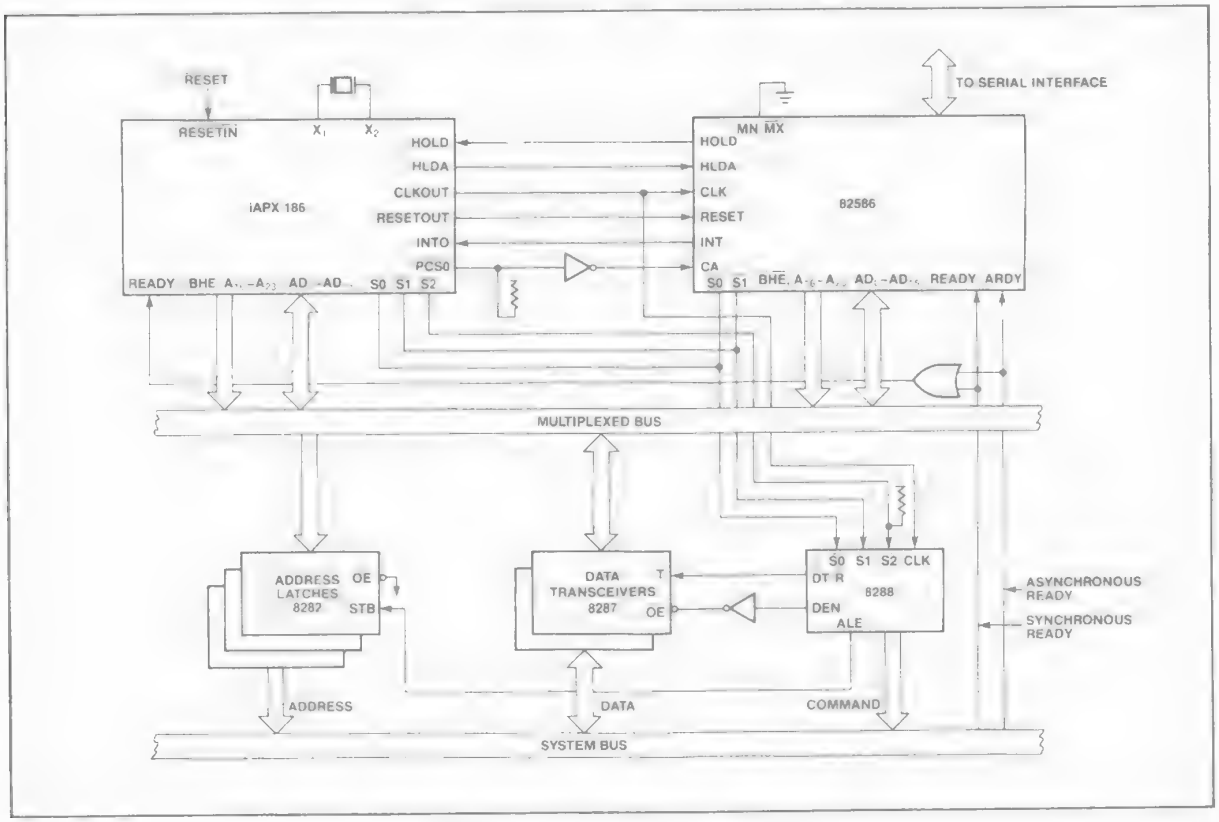

Figure 10. iAPX 186/82586 System

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For 8086/8088-based systems, the 82285 is used as a clock generator for the 82586 system clock and the 8259A as an interrupt controller. The 8288 Bus Controller is common as both the CPU and the 82586 have the same data transfer timing. A bus arbiter is also needed to convert to/from the 82586 HOLD/HLDA from/to the 8086/8088 RQ/GT. This configuration is shown in Figure 11.

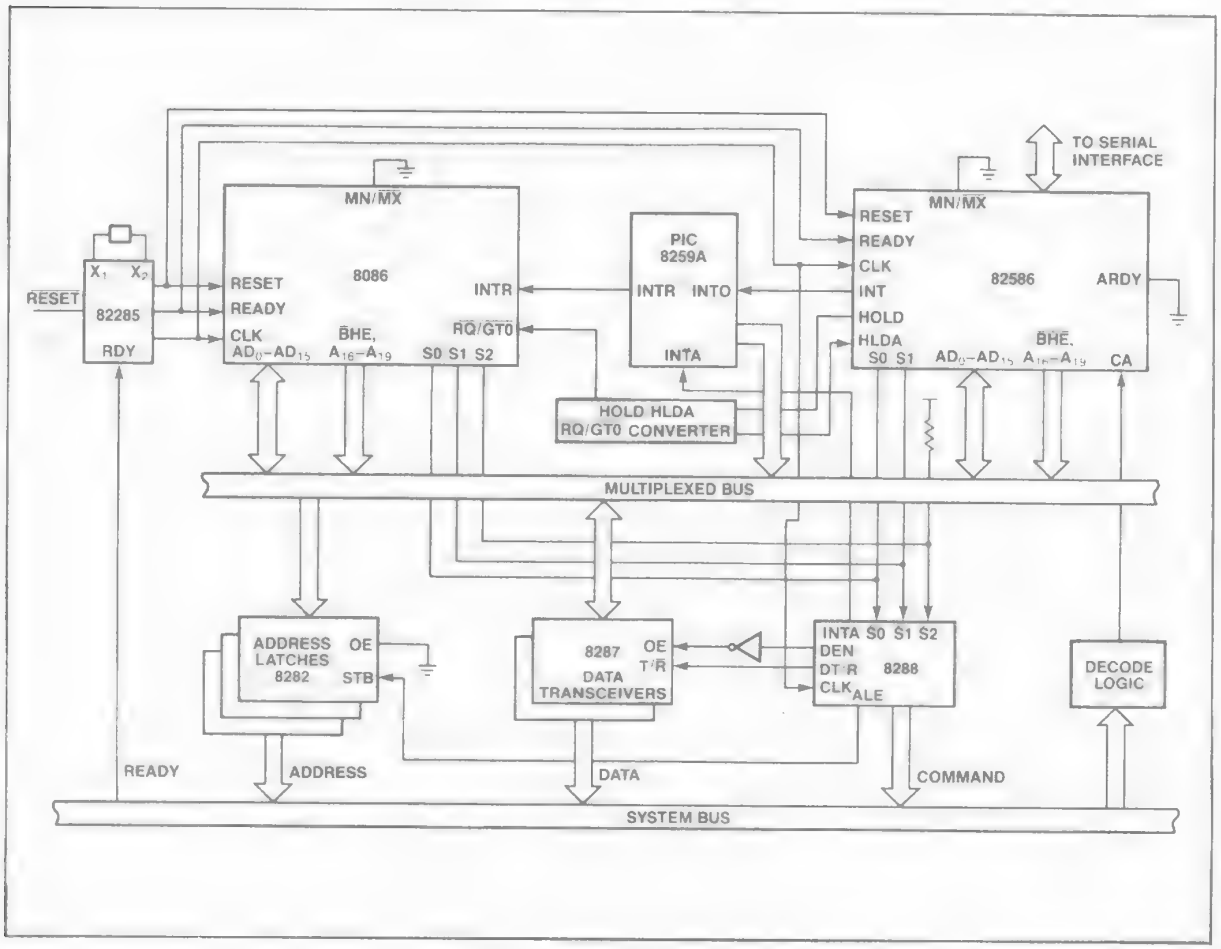

Figure 11. 8086/82586 System

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A third system configuration shown in Figure 12 is a dual-port RAM-based system. In this configuration, the bus traffic between the 82586 and shared memory (via port B) is isolated from system bus traffic. Using such a configuration, high-bandwidth peripherals like the 82586 can operate with shared memory using its own local bus, leaving the system bus free for the CPU and other peripherals such as a display controller, with access to shared memory via Port A.

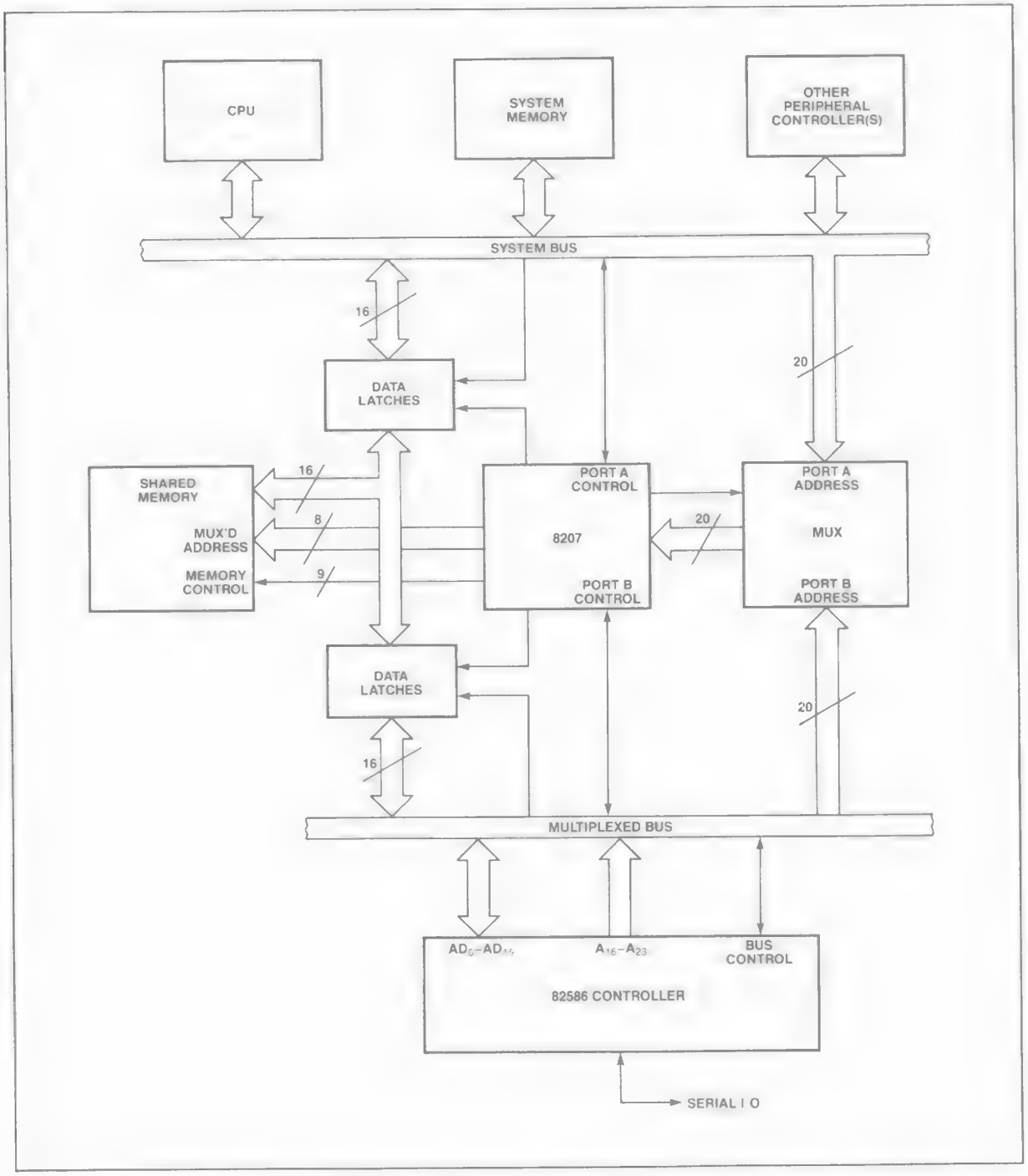

Figure 12. Dual-Port RAM-Based System

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Emerging Applications

The availability of low-cost VLSI controllers to serve Ethernet local-area networks is also stimulating other high-speed serial applications. The serial backplane is a form of a local area network within a cabinet. A high-speed "Serial backplane" is used to connect modular subsystems within a box. For example, a high-feature copier will have modular designs for the display/control panel, feeder, sorter, camera and developing functions. By replacing multiconductor busses with a single serial backplane, costs are reduced while improving design flexibility, reliability and modularity for future growth (Figure 13).

A logical extension of the serial backplane within the cabinet is serial connection for local clusters of peripherals around a basic work station, for example (Figure 14). While maintaining a connection to the "public" local-area network, Ethernet, local peripherals such as printers or disk storage can be added to the work station via a separate serial connection. Such serial peripheral connections also result in more flexible system designs by allowing for modular growth. By using the 82586 programmable functions, the frame length, network size and transmission speed can be tailored to the specific serial backplane or peripheral connection environment.

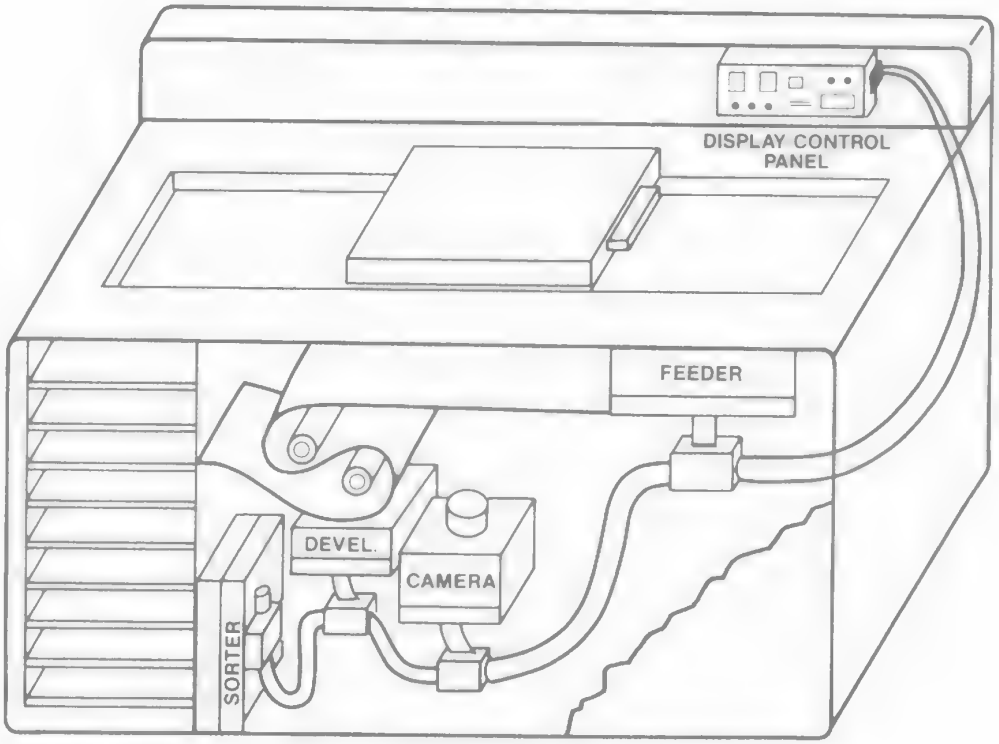

Figure 13. Serial Backplane

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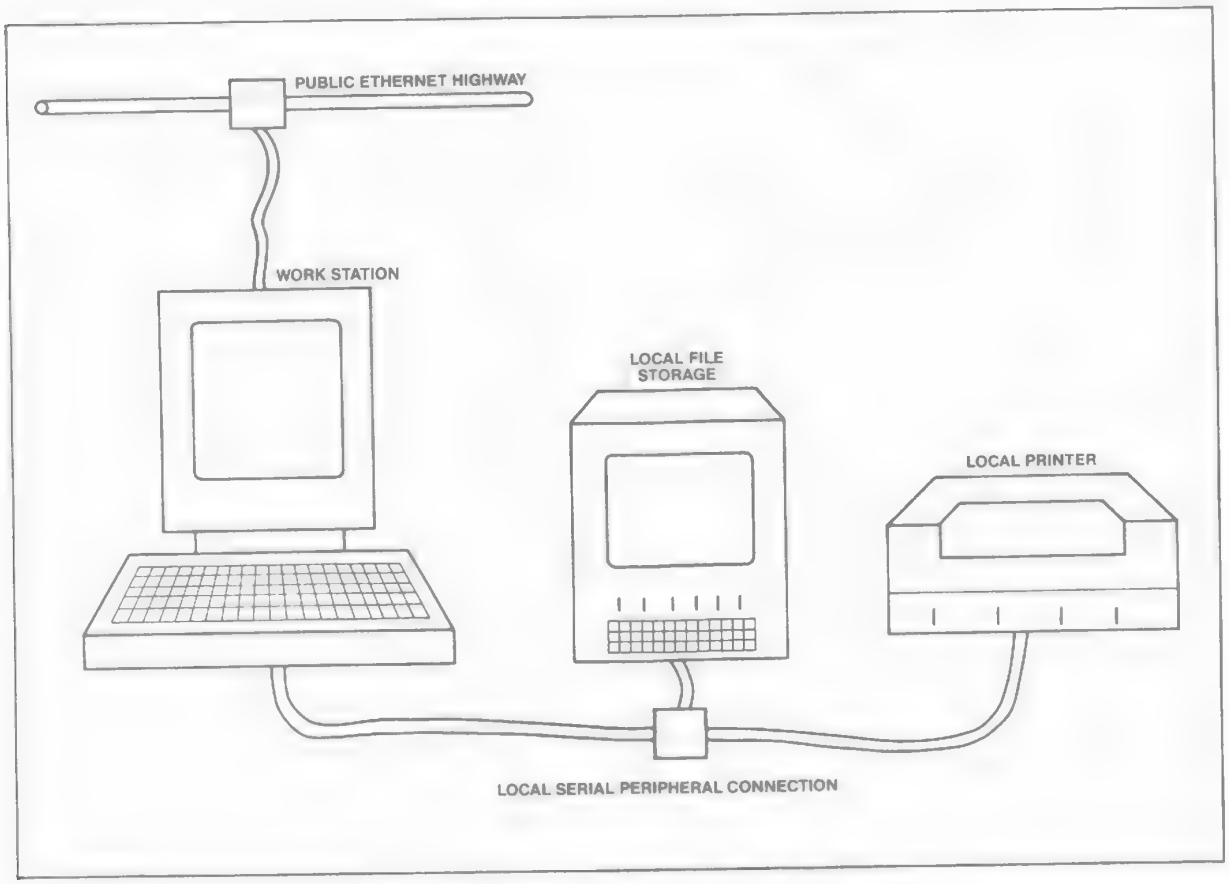

Figure 14. Local Peripheral Interconnection

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PRELIMINARY

82720
GRAPHICS DISPLAY CONTROLLER

- High-Performance Graphics for Siggraph Core-, N.A.P.L.P.S.- and ANSI VDI-Compatible or Custom Systems
- Displays Low-to-High Resolution Images
- Draws Characters, Points, Lines, Arcs and Rectangles
- Supports Monochrome, Greyscale or Color Displays
- Zooms, Pans and Windows Through a 1/2-Mbyte Display Memory
- Extremely Flexible Programmable Screen Display, Blanking and Sync Formats
- Compatible with Intel's MCS®-51 and iAPX 88/86/186 Microprocessor Families
- High-Level Commands Off Load the Master Processor from Bit Map Loading and Screen Refresh Tasks
- Supports Graphics, Character, and Mixed Display Modes

FUNCTIONAL DESCRIPTION

The 82720 Graphics Display Controller (GDC) is an intelligent microprocessor peripheral designed to drive high-performance raster-scan computer graphics and character CRT displays. Positioned between the video display memory and an Intel microprocessor bus, the GDC performs the tasks needed to generate the raster display and manage the display memory. Processor software overhead is minimized by the GDC's sophisticated instruction set, graphics figure drawing, and DMA transfer capabilities. The display memory supported by the GDC can be configured in any number of formats and sizes up to 256K 16-bit words. The display can be zoomed while partitioned screen areas can be independently scrolled and panned. With its light pen input and multiple controller capability, the GDC is ideal for most computer graphics applications. Systems implemented with the GDC can be designed to be compatible with standards such as Siggraph Core, N.A.P.L.P.S., and ANSI VDI or custom implementations.

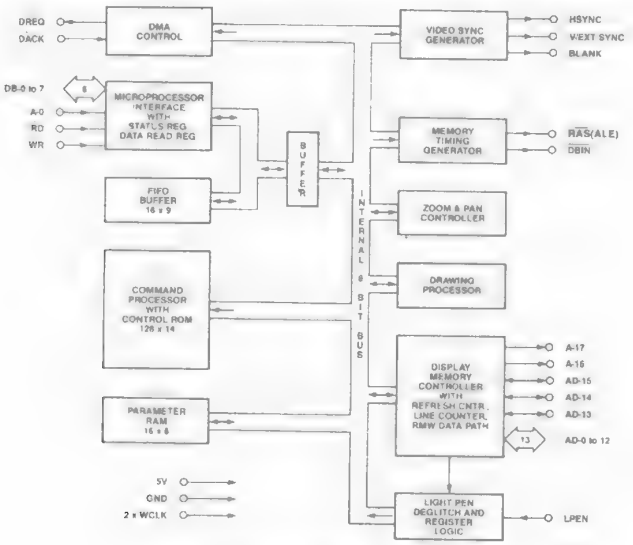

Figure 1. Block Diagram

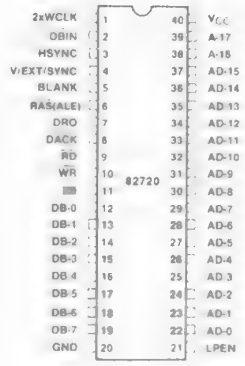

Figure 2. Pin Configuration

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NOVEMBER 1982
ORDER NUMBER: 210655-001

Table 1. Pin Description

Symbol	Pin No.	Type	Name and Description
2XWCLK	1	I	**Clock Input**
$\overline{DBIN}$	2	O	**Display Bus Input:** Read strobe output used to read display memory data into the GDC.
HSYNC	3	O	**Horizontal Sync:** Output used to initiate the horizontal retrace of the CRT display.
V/EXT SYNC	4	I/O	**Vertical Sync:** Output used to initiate the vertical retrace of the CRT display. In slave mode, this pin is an input used to synchronize the GDC with the master raster timing device.
BLANK	5	O	**Blank:** Output used to suppress the video signal.
$\overline{RAS}$ (ALE)	6	O	**Row Address Strobe (Address Latch Enable):** Output used to start the control timing chain when used with dynamic RAMs. When used with static RAMs, this signal is used to demultiplex the display address/data bus.
DRQ	7	O	**DMA Request:** Output used to request a DMA transfer from a DMA controller (8237) or I/O processor (8089).
$\overline{DACK}$	8	I	**DMA Acknowledge:** Input used to acknowledge a DMA transfer from a DMA controller or I/O processor.
$\overline{RD}$	9	I	**Read:** Input used to strobe GDC Data into the microprocessor.
$\overline{WR}$	10	I	**Write:** Input used to strobe microprocessor data into the GDC.
A0	11	I	**Register Address:** Input used to select between commands and data read or written.
DB0 DB1 DB2 DB3 DB4 DB5 DB6 DB7	12 13 14 15 16 17 18 19	I/O	**Bidirectional Microprocessor Data Bus Line:** Input enabled by WR. Output enabled by RD.
GND	20		**Ground.**
V_{CC}	40		**+5V Power Supply**
A_{17}	39	O	**Graphics Mode:** Display Address Bit 17 Output **Character Mode:** Cursor Output **Mixed Mode:** Cursor and Image Mode Flag
A_{16}	38	O	**Graphics Mode:** Display Address Bit 16 Output **Character Mode:** Line Counter Bit 3 **Mixed Mode:** Attribute Blink and Line Counter Reset
A_{15} A_{14} A_{13}	37 36 35	I/O	**Graphics Mode:** Display Address/Data Bits 13–15 **Character Mode:** Line Counter Bits 0–2 Output **Mixed Mode:** Display Address/Data Bits 13–15
AD_{12} AD_{11} AD_{10} AD_9 AD_8 AD_7 AD_6 AD_5 AD_4 AD_3 AD_2 AD_1 AD_0	34 33 32 31 30 29 28 27 26 25 24 23 22	I/O	**Display Address/Data Bits 0–12**
LPEN	21	I	**Light Pen Detect Input**

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Microprocessor Bus Interface

Control of the GDC by the system microprocessor is achieved through an 8-bit bidirectional interface. The status register is readable at any time. Access to the FIFO buffer is coordinated through flags in the status register.

Command Processor

The contents of the FIFO are interpreted by the command processor. The command bytes are decoded and the succeeding parameters are distributed to their proper destinations within the GDC. The bus interface has priority over the command processor when both access the FIFO simultaneously.

DMA Control

The DMA control circuitry in the GDC coordinates data transfers when using an external DMA controller. The DMA Request and Acknowledge handshake lines directly interface with an 8257, 8237, iAPX186 DMA controller, or 8089 I/O processor, so that display data can be moved between the microprocessor memory and the display memory.

Parameter RAM

The 16-byte RAM stores parameters that are used repetitively during the display and drawing processes. In character mode, the RAM holds four sets of partitioned display area parameters. In graphics mode, the RAM holds the drawing pattern and graphics character.

Video Sync Generator

Based on the clock input, the sync logic generates the raster timing signals for almost any interlaced, non-interlaced, or "repeat field" interlaced video format. The generator is programmed during the idle period following a reset. In video sync slave mode, it coordinates timing between the GDC and another video source.

Memory Timing Generator

The memory timing circuitry provides two memory cycle types: a two-clock period refresh cycle and the read-modify-write (RMW) cycle which takes four clock periods. The memory control signals needed to drive the display memory devices are easily generated from the GDC's $\overline{RAS}$(ALE) and $\overline{DBIN}$ outputs.

Zoom and Pan Controller

Based on the programmable zoom display factor and the display area parameters in the parameter RAM, the zoom and pan controller determines when to advance to the next memory address for display refresh and when to go on to the next display area. A horizontal zoom is produced by slowing down the display refresh rate while maintaining the video sync rates. Vertical zoom is accomplished by repeatedly accessing each line a number of times equal to the horizontal repeat. Once the line count for a display area is exhausted, the controller accesses the starting address and line count of the next display area from the parameter RAM. The system microprocessor, by modifying a display area starting address, allows panning in any direction, independent of the other display areas.

Drawing Processor

The drawing processor contains the logic necessary to calculate the addresses and positions of the pixels of the various graphics figures. Given a starting point and the appropriate drawing parameters, the drawing processor needs no further assistance to complete the figure drawing.

Display Memory Controller

The display memory controller's tasks are numerous. Its primary purpose is to multiplex the address and data information in and out of the display memory. It also contains the 16-bit logic units used to modify the display memory contents during RMW cycles, the character mode line counter, and the refresh counter for dynamic RAMs. The memory controller apportions the video field time between the various types of cycles.

Light Pen Debouncer

Only if two rising edges on the light pen input occur at the same point during successive video fields are the pulses accepted as a valid light pen detection. A status bit indicates to the system microprocessor that the light pen register contains a valid address.

System Operation

The GDC is designed to work with Intel microprocessors to implement high-performance computer graphics systems. System efficiency is maximized through partitioning and a pipelined architecture. At the lowest level, the GDC generates the basic video

raster timing, including sync and blanking signals. Partitioned areas on the screen and zooming are also accomplished at this level. At the next level, video display memory is modified during the figure drawing operations and data moves. Third, display memory address are calculated pixel by pixel as drawing progresses. Outside the GDC at the next level, preliminary calculations are done to prepare drawing parameters. At the fifth level, the picture must be represented as a list of graphics figures drawable by the GDC. Finally, this representation must be manipulated, stored and communicated. The GDC takes care of the high-speed and repetitive tasks required to implement graphics systems.

GENERAL OVERVIEW

In order to minimize system bus loading, the 82720 uses a private video memory for storage of the video image. Up to 512K bytes of video memory can be supported. For example, this is sufficient capacity to store a 2048 x 2048 bit image. Using 1 bit per picture-element (pixel), this translates into 2048 x 2048 pixels. Images can be generated on the screen by:

—Drawing commands
—Program-Controlled Transfers
—DMA Transfers from System Memory

The 82720 can be configured to support a wide variety of graphics applications. It can support:

—High Dot Rates
—Color planes
—Horizontal split screen
—Character-oriented Displays
—Multiplexed Graphic and Character Display

GRAPHIC DISPLAY CONFIGURATIONS

The 82720 provides the flexibility to handle a wide variety of graphic applications. This flexibility results from having its own private video memory for storage of the graphics image. The organization of this memory determines the performance, the number of bits/pixel and the size of the display. Several different video memory organizations are examined in the following paragraphs.

In the simplest 82720 system, the memory can store up to a 2048 x 2048 x 1 bit image. It can display a 1024 x 1024 x 1 bit section of the image at a maximum dot rate of 80 MHz. In this configuration, only 1 bit/pixel is used.

By partitioning the memory into multiple banks, color, greyscale and higher bandwidth displays can be supported. By adding various amounts of external logic, many cost/performance tradeoffs for both display and drawing are realizable.

The video memory can be partitioned into 4 banks, each 1024 x 1024 bits. By selecting all 4 memory banks during display, 4 bits/pixel can be provided by a single 82720. Each bank of video memory contributes 1 bit to each pixel. This configuration can support color monitors with a maximum dot shift rate of 80 MHz.

Higher performance may be achieved by using multiple 82720s. Multiple 82720s can be used to support mutliple display windows, increased drawing speed, or increased bits per pixel. For display windows, each 82720 controls one window of the display. For increased drawing speed, multiple 82720s are operated in parallel. For increased bits/pixel, each 82720 contributes a portion of the number of bits necessary for a pixel.

CHARACTER DISPLAY CONFIGURATION

Although the 82720 is intended primarily for raster-scan graphics, it can be used as a character display controller. The 82720 can support up to 8K by 13 bits of private video memory in this configuration (1 character = 13 bits). This is sufficient memory to store 4 screens of data containing 25 rows by 80 characters. The 82720 can display up to 100 rows by 256 characters. Smooth vertical scrolling of the display is also supported.

MULTIPLEXED DISPLAY CONFIGURATION

The GDC can support a mixed display system for both graphic and character information. This capability allows the display screen to be partitioned between graphic and character data. It is possible to switch between one graphic display window and one character display window with raster line resolution. A maximum of 256K bytes of video memory is supported in this mode: Half is for graphic data, half is for character data. In graphic mode, a one megapixel image can be stored and displayed. In character mode, 64K, 16-bit characters can be stored. Up to 100 rows by 256 characters can be displayed.

DETAILED OPERATIONAL DESCRIPTION

The GDC can be used in one of three basic modes —Graphics Mode, Character Mode and Mixed Mode. This section of the data sheet describes the following for each mode:

1. Memory organization
2. Display timing
3. Special Display functions
4. Drawing and writing

Graphics Mode Memory Organization

The Display Memory is organized into 16-bit words. Since the display memory can be larger than the CRT display itself, two width parameters must be specified: display memory width and display width. The Display width (in words) is selected by a parameter of the Reset command. The Display memory width (in words) is selected by a parameter of the Pitch command. The height of the Display memory can be larger than the display itself. The height of the Display is selected by a parameter of the Reset command. The height of the Display memory defaults to the Total Display memory size divided by the display memory width. The GDC can address up to 4Mbits (512Kbytes) of display RAM in graphics mode.

Graphics Mode Display Timing

All raster blanking and display timings of the GDC are a function of the input clock frequency. Sixteen bits of data are read from the RAM and loaded into a shift register in each two clock period access cycle. The Address and Data busses of the GDC are multiplexed. In the first part of the cycle, the address of the word to be read is latched into an external demultiplexer. In the second part of the cycle the data is read from the RAM and loaded into the shift register. Since all 16 bits of data are to be displayed, the dot clock is 8x the GDC clock or 16x the Read cycle frequency.

The Vertical Front Porch, Sync, and Back Porch timings are also defined by parameters of the Reset command. They are multiples of the Raster Line times. The cursor is not visible in graphics mode.

Another Reset command parameter selects interlaced or non-interlaced mode. When the interlaced mode is selected, a bit in the parameter RAM can define Wide Display Mode. In this mode, while data is being sent to the screen, the display address counter is incremented by two rather than one. This allows the display memory to be configured to deliver 32 bits from each display read cycle.

The V Sync command specifies whether the V Sync Pin is an input or an output. If the V Sync Pin is an output, the GDC generates the raster timing for the display and other CRT controllers can be synchronized to it. If the V Sync pin is an input, the GDC can be synchronized to any external vertical Sync signal.

Graphics Mode Special Display Functions:

WINDOWING

The GDC's Graphics Mode Display can be divided into two windows on the screen, upper and lower. The windows are defined by parameters written into the GDC's parameter RAM. Each window is specified by a starting address and a window length in lines. If the second window is not used, the first window parameters should be specified to be the same as the active display size.

ZOOMING

A parameter of the GDC's zoom command allows zooming by effectively increasing the size of the dots on the screen. This is accomplished vertically by repeating the same display line. The number of times it is repeated is determined by the display zoom factor parameter. Horizontally, zoom is accomplished by extending each display word cycle and displaying fewer words per line, according to the zoom factor. It is the responsibility of the microprocessor controlling the GDC to provide the shift register clock circuitry with the zoom factor required to slow down the shift registers to the appropriate speed. The frequency of the 2XWCLK should not be changed. The zoom factor must be set to a known state upon initialization.

PANNING

Panning is accomplished by changing the starting address of the display window. In this way, panning is possible in any direction, vertically on a line by line basis and horizontally on a word by word basis.

Graphics Mode Drawing and Writing

The GDC can draw dotted lines, arcs, circles, rectangles, slanted rectangles, characters, slanted characters, filled rectangles. Direct access to the bit map is also provided via the DMA Commands and the Read or write data commands.

MEMORY MODIFICATION

All drawing and writing functions take place at the location in the display RAM specified by the cursor. The cursor is not displayed in Graphics Mode. The cursor location is modified by the execution of drawing, reading or writing commands. The cursor will move to the bit following the last bit accessed.

Each bit is drawn by executing a Read-Modify-Write cycle on the display RAM. These R/M/W cycles require four 2XWCLK cycles to execute. Write Data (WDAT), Read Data (RDAT), DMA write (DMAW) and DMA read (DMAR) commands can be used to examine or modify one to 16 bits in each word during each R/M/W cycle. All other graphics drawing commands modify one bit per R/M/W cycle.

An internal 16-bit Mask register determines which bit(s) in the accessed word are to be modified. A one in the Mask register allows the bit in the display RAM to be modified by the R/M/W cycle. A zero in the mask register prevents the GDC from modifying the bit in the display RAM.

The mask must be set by the Mask Command prior to issuing the WDAT and DMAW. The Mask register is automatically set by the CURS Command and manipulated by the graphics commands.

The display RAM bits can be modified in one of four ways. They can be set to 1, reset to 0, complemented or replaced by a pattern.

When replace by a pattern mode is selected, lines, arcs and rectangles will be drawn using the 16-bit pattern in parameter RAM bytes 8 and 9.

In set, reset, or complement mode, parameter RAM bytes 8 and 9 act as another level of masking for line arc and rectangle drawing. As each 16-bit segment of the line or arc is drawn, it is checked against the pattern in the Parameter RAM. If the pattern RAM bit is a one, the display RAM bit will be set, reset, or complemented per the proper modes. If the pattern RAM bit is a zero, the Display RAM bit won't be modified.

When replace by pattern mode is selected, the graphics character and fill commands will cause the 8 x 8 pattern in parameter RAM bytes 8 to 15 to be written directly into the display RAM in the appropriate locations.

In set, reset, or complement mode, the 8 x 8 pattern in parameter RAM bytes 8 to 15 act as a mask pattern for graphics character or fill commands. If the appropriate parameter RAM bit is set, the display RAM bit will be modified. If the parameter RAM bit is zero, the display RAM bit will not be modified. These modes are selected by issuing a WDAT command without parameters before issuing graphics commands. The pattern in the parameter RAM has no effect on WDAT, RDAT, DMAW, or DMAR operations.

READING AND DRAWING COMMANDS

After the modification mode has been set and the parameter RAM has been loaded, the final drawing parameters are loaded via the figure specify (FIGS) command. The first parameter specifies the direction in which drawing will occur and the figure type to be drawn. This parameter is followed by one to five more parameters depending on the type of character to be drawn.

The direction parameter specifies one of eight octants in which the drawing or reading will occur. The effect of drawing direction on the various figure types is shown in the figure below.

RDAT, WDAT, DMAR, and DMAW Operations move through the Display memory as shown in the "DMA" Column.

The other parameters required to set up figure reading or drawing are shown in the following figure.

DRAWING TYPE	DC	D	D2	D1	DM
INITIAL VALUE*	0	[illegible]	[illegible]	1	1
LINE	ΔI	2 ΔD ΔI	2(↑ΔD ΔI)	2 ΔD	—
ARC**	r sin φ↑	r 1	2(r 1)	1	r sin θ↓
RECTANGLE	3	A 1	B 1	1	A 1
AREA FILL	B 1	[illegible]	[illegible]	—	—
GRAPHIC CHARACTER***	B 1	A	A	—	—
READ & WRITE DATA	W 1	—	—	—	—
DMAW	D 1	C 1	—	—	—
DMAR	D 1	C 1	(C 1)/2 ≠	—	—

* INITIAL VALUES FOR THE VARIOUS PARAMETERS ARE LOADED DURING THE HANDLING OF THE FIGS OP CODE BYTE.
** CIRCLES ARE DRAWN WITH 8 ARCS, EACH OF WHICH SPAN 45°, SO THAT SIN φ = 1/√2 AND SIN θ = 0.
*** GRAPHIC CHARACTERS ARE A SPECIAL CASE OF BIT-MAP AREA FILLING IN WHICH B AND A = 8. IF A = 8 THERE IS NO NEED TO LOAD D AND D2.

WHERE:
1 – ALL ONES VALUE.
ALL NUMBERS ARE SHOWN IN BASE 10 FOR CONVENIENCE. THE GDC ACCEPTS BASE 2 NUMBERS (2'S COMPLEMENT NOTATION WHERE APPROPRIATE)
– – NO PARAMETER BYTES SENT TO GDC FOR THIS PARAMETER.
ΔI – THE LARGER OF ΔX OR ΔY (DEPENDENT AXIS)
ΔD – THE SMALLER OF ΔX OR ΔY. (INDEPENDENT AXIS)
r – RADIUS AT CURVATURE, IN PIXELS.
φ – ANGLE FROM MAJOR AXIS TO END AT THE ARC. φ ≤ 45°.
θ – ANGLE FROM MAJOR AXIS TO START AT THE ARC. θ ≤ 45°.
↑ – ROUND UP TO THE NEXT HIGHER INTEGER.
↓ – ROUND DOWN TO THE NEXT LOWER INTEGER.
A – NUMBER OF PIXELS IN THE INITIALLY SPECIFIED DIRECTION.
B – NUMBER OF PIXELS IN THE DIRECTION AT RIGHT ANGLES TO THE INITIALLY SPECIFIED DIRECTION.
W – NUMBER OF WORDS TO BE ACCESSED
C – NUMBER OF BYTES TO BE TRANSFERRED IN THE INITIALLY SPECIFIED DIRECTION. (TWO BYTES PER WORD IF WORD TRANSFER MODE IS SELECTED.)
D – NUMBER OF WORDS TO BE ACCESSED IN THE DIRECTION AT RIGHT ANGLES TO THE INITIALLY SPECIFIED DIRECTION.
DC – DRAWING COUNT PARAMETER WHICH IS ONE LESS THAN THE NUMBER OF RMW CYCLES TO BE EXECUTED.
DM – DOTS MASKED FROM DRAWING DURING ARC DRAWING.
≠ – NEEDED ONLY FOR WORD READS.

Figure 3. Drawing Parameter Details

The independent axis called out in the table is either horizontal or vertical. The independent axis is defined as the axis of the longest component of the vector. The dependent axis is the axis of the shortest component of the vector. After the parameters have been set, line, arc, circle, rectangle or slanted rectangle drawing operations are initiated by the Figure Draw (FIGD) command. Character, slanted character, area fill and slanted area fill drawing operations are initiated by the Graphics Character Draw (GCHRD) command. DMA transfers are initiated by the DMA Read or Write (DMAR or DMAW) commands. Data Read Operations are initiated by the Read Data (RDAT) Command. Data Write Operations are initiated by writing a parameter after the WDAT command.

The Area Fill operation steps and repeats the 8 x 8 graphics character pattern draw operation to fill a rectangular area. If the size of the rectangle is not an integral number of 8 x 8 pixels, the GDC will automatically truncate the pattern at the edges furthest from the starting point.

The Graphics Character Drawing capability can be modified by the Graphics Character Write Zoom Factor (GCHR) parameter of the zoom command. The zoom write factor may be set from 1 to 16 (by using from 0 to 15 in the parameter). Each dot will be repeated in memory horizontally and vertically (adjusted for drawing direction) the number of times specified by the zoom factor.

Arcs which do not start on an octant boundary can be drawn with 2 commands. One which draws from the octant boundary to the end of the arc followed by a command which erases the arc from the arc from the octant boundary to the beginning of the arc.

The WDAT Command can be used to rapidly fill large areas in memory with the same value. In the graphics mode, the LS Bit of the Parameter is used as the pattern for the R/M/W operations.

Character Mode Memory Organization

In character mode, the Display memory is organized into up to 8K characters of up to 13 bits each.

The display memory can be larger than the display itself. The display width (in characters) is a parameter of the reset command. The display memory width (in characters) is a parameter of the Pitch Command. The height of the display (in lines) is a parameter of the Reset Command. The display memory height is determined by dividing the number of display memory words by the pitch.

In character mode, the display works almost exactly as it does in graphics mode. The differences lie in the fact that data read from the display RAM is used to drive a character generator EPROM, as well as color, greyscale, or attribute logic if desired. In Character mode, address bits 13–16 become line counter outputs used to select the proper line of the character generator, and the address 17 output becomes the cursor output.

Character Mode Display Timing

In character mode, the display timing works as it does in graphics mode. In addition, the Address 17 ouput becomes cursor output. The characteristics of the cursor are defined by parameters of the cursor and Character Characteristics (CCHAR) Command. One bit allows the cursor output to be enabled or disabled. The height of the cursor is programmable by selecting the top and bottom line between which the cursor will appear. The blink rate is also programmable. The parameter selects the number of frame times that the cursor will be inactive and active, resulting in a 50% duty cycle cursor blinking at 2x the rate specified by the parameter.

Character Mode Special Display Functions

WINDOWING

The GDC's Character Mode display can be partitioned into one to four windows on the screen. The windows are defined by parameters written into the GDC's Parameter RAM. Each window is specified by a starting address and a window length in characters.

If windowing is not required, the first window length should be specified to be the same as the active display size.

ZOOMING AND PANNING

In character mode, zooming and pan handling commands function the same way as in Graphics Mode.

Character Mode Drawing and Writing

The GDC can read or write characters of up to 13 bits into or out of the Display RAM.

All reading and writing functions take place at the display RAM Location specified by the cursor. The cursor location can be read by issuing the CURD Command. The cursor can be moved anywhere within the display memory by the CURS command. The cursor location is also modified by the execution of character read or write commands.

Each character is written or read via a Read/ Modify/ Write cycle. Which bit(s) in the character to be modified is determined by the mask register. The mask register can be used to change character codes without modifying attribute bits or vice-versa. The Replace with pattern, Set, Reset and Complement modes work exactly as they do in graphics mode, with the exception that the parameter RAM Pattern is not used. The pattern used is a parameter of the WDAT Command.

The Figure Specify (FIGS) command must be set to Character Display mode, as well as specify the direction the cursor will be moved by read or write data commands.

In character mode, the FIGD and GCHRD commands are not used.

Mixed Mode Memory Organization

In mixed mode, the display memory is organized into up to 64K words of 16 bits.

The display height and width are programmable by the same reset command parameters as in the graphics and character modes. The display memory width (in words) is a parameter of the Pitch Command and the height of the display memory is determined by dividing the number of display memory words by the pitch.

An image mode signal is used to switch the external circuitry between graphics and character modes in two display windows.

In a graphics window, the GDC works as it does in pure graphics mode, but on a smaller total memory space (64K words vs 512K words).

In a character window, the GDC works as it does in pure character mode, but the line counter must be implemented externally. The counter is clocked by the horizontal sync pulse and reset by a signal supplied by the GDC.

In mixed mode, the GDC provides both a cursor and an attribute blink timing signal.

Mixed Mode Display Timing

In mixed mode, the display timing works exactly as it does in graphics mode.

In addition, A16 becomes a Multiplexed Attribute and Clear Line Counter signal and A17 becomes a multiplexed cursor and image mode signal. A16 provides an active high line counter reset signal which can be latched on the trailing edge of the horizontal sync pulse. During the active display line time, A16 provides blink timing for external attribute circuitry. This signal blinks at 1/2 the blink rate of the cursor with a 75% on, 25% off duty cycle. A17 provides a signal which selects between graphics or character display, which can be latched on the trailing edge of the horizontal sync pulse. During the active display time, A17 provides the cursor signal. The cursor timing and characteristics are defined in exactly the same way as in pure character mode.

Mixed Mode Special Display Functions

WINDOWING

The GDC supports from one to four display windows in mixed mode. They can independently be programmed into either graphics or character mode determined by the state of two bits in the parameter RAM. The window location in display memory and size also determined by parameters in the parameter RAM.

ZOOMING AND PANNING

In mixed mode, zooming and panning commands function the same as in graphics and character mode.

Mixed Mode Drawing and Writing

In mixed mode, the GDC can write or draw in exactly the same ways as in both graphics and character modes. In addition, the FIGS command has a parameter GD (Graphics Drawing Flag) which sets the image mode signal to the proper state for External Graphics or Character Circuitry.

DEVICE PROGRAMMING

The GDC occupies two addresses on the system microprocessor bus through which the GDC's status register and FIFO are accessed. Commands and parameters are written into the GDC FIFO and are differentiated on address bit A0. The status register or

A0	READ	WRITE
0	STATUS REGISTER	PARAMETER INTO FIFO
1	FIFO READ	COMMAND INTO FIFO

Figure 4. GDC Microprocessor Bus Interface Registers

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the FIFO can be read as selected by the address line. Commands to the GDC take the form of a command byte followed by a series of parameter bytes as needed for specifying the details of the command. The command processor decodes the commands, unpacks the parameters, loads them into the appropriate registers within the GDC and initiates the required operations.

The commands available in the GDC can be organized into five categories as described in figure 5.

VIDEO CONTROL COMMANDS
1. RESET: RESETS THE GDC TO ITS IDLE STATE.
2. SYNC: SPECIFIES THE VIDEO DISPLAY FORMAT.
3. VSYNC: SELECTS MASTER OR SLAVE VIDEO SYNCHRONIZATION MODE
4. CCHAR: SPECIFIES THE CURSOR AND CHARACTER ROW HEIGHTS.

DISPLAY CONTROL COMMANDS
1. START: ENDS IDLE MODE AND UNBLANKS THE DISPLAY.
2. BCTRL: CONTROLS THE BLANKING AND UNBLANKING OF THE DISPLAY.
3. ZOOM: SPECIFIES ZOOM FACTORS FOR THE DISPLAY AND GRAPHICS CHARACTERS WRITING.
4. CURS: SETS THE POSITION OF THE CURSOR IN DISPLAY MEMORY.
5. PRAM: DEFINES STARTING ADDRESSES AND LENGTHS OF THE DISPLAY AREAS AND SPECIFIES THE EIGHT BYTES FOR THE GRAPHICS CHARACTER.
6. PITCH: SPECIFIES THE WIDTH OF THE X DIMENSION OF DISPLAY MEMORY.

DRAWING CONTROL COMMANDS
1. WDAT: WRITES DATA WORDS OR BYTES INTO DISPLAY MEMORY
2. MASK: SETS THE MASK REGISTER CONTENTS.
3. FIGS: SPECIFIES THE PARAMETERS FOR THE DRAWING PROCESSOR.
4. FIGD: DRAWS THE FIGURE AS SPECIFIED ABOVE.
5. GCHRD: DRAWS THE GRAPHICS CHARACTER INTO DISPLAY

MEMORY. DATA READ COMMANDS
1. RDAT: READS DATA WORDS OR BYTES FROM DISPLAY MEMORY.
2. CURD: READS THE CURSOR POSITION.
3. LPRD: READS THE LIGHT PEN ADDRESS.

DMA CONTROL COMMANDS
1. DMAR: REQUESTS A DMA READ TRANSFER.
2. DMAW: REQUESTS A DMA WRITE TRANSFER.

Figure 5. GDC Command Summary

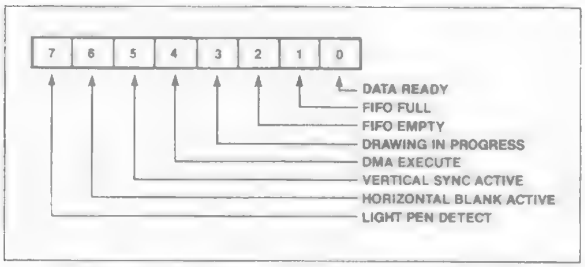

Figure 6. Status Register (SR)

Status Register Flags

SR-7: Light Pen Detect: When this bit is set to 1, the light pen address (LAD) register contains a deglitched value that the system microprocessor may read. This flag is reset after the 3-byte LAD is moved into the FIFO in response to the light pen read command.

SR-6: Horizontal Blanking Active: A 1 value for this flag signifies that horizontal retrace blanking is currently underway.

SR-5: Vertical Sync: Vertical retrace sync occurs while this flag is a 1. The vertical sync flag coordinates display format modifying commands to the blanked interval surrounding vertical sync. This eliminates display disturbances.

SR-4: DMA Execute: This bit is a 1 during DMA data transfers.

SR-3: Drawing in Progress: While the GDC is drawing a graphics figure, this status bit is a 1.

SR-2: FIFO Empty: This bit and the FIFO Full flag coordinate system microprocessor accesses with the GDC FIFO. When it is 1, the Empty flag ensures that all the commands and parameters previously sent to the GDC have been processed.

SR-1: FIFO Full: A 1 at this flag indicates a full FIFO in the GDC. A 0 ensures that there is room for at least one byte. This flag needs to be checked before each write into the GDC.

SR-0: Data Ready: When this flag is a 1, it indicates that a byte is available to be read by the system microprocessor. This bit must be tested before each read operation. It drops to a 0 while the data is transferred from the FIFO into the microprocessor interface data register.

FIFO Operation & Command Protocol

The first-in, first-out buffer (FIFO) in the GDC handles the command dialogue with the system microprocessor. This flow of information uses a half-duplex technique, in which the single 16-location FIFO is used for both directions of data movement, one direction at a time. The FIFO's direction is controlled by the system microprocessor thorugh the GDC's command set. The microprocessor coordinates these transfers by checking the appropriate status register bits.

The command protocol used by the GDC requires the differentiation of the first byte of a command sequence from the succeeding bytes. This first byte contains the operation code and the remaining bytes carry parameters. Writing into the GDC causes the FIFO to store a flag value alongside the data byte to signify whether the byte was written into the command or the parameter address. The command processor in the GDC tests this bit as it interprets the entries in the FIFO.

The receipt of a command byte by the command processor marks the end of any previous operation. The number of parameter bytes supplied with a command is cut short by the receipt of the next command byte. A read operation from the GDC to the microprocessor can be terminated at any time by the next command.

The FIFO changes direction under the control of the system microprocessor. Commands written into the GDC always put the FIFO into write mode if it wasn't in it already. If it was in read mode, any read data in the FIFO at the time of the turnaround is lost. Commands which require a GDC response, such as RDAT, CURD and LPRD, put the FIFO into read mode after the command is interpreted by the GDC's command processor. Any commands and parameters behind the read-evoking command are discarded when the FIFO direction is reversed.

Read-Modify-Write Cycle

Data transfers between the GDC and the display memory are accomplished using a read-modify-write (RMW) memory cycle. The four clock period timing of the RMW cycle is used to: 1) output the address, 2) read data from the memory, 3) modify the data, and 4) write the modified data back into the initially selected memory address. This type of memory cycle is used for all interactions with display memory including DMA transfers, except for the two clock period display and RAM refresh cycles.

The operations performed during the modify portion of the RMW cycle merit additional explanation. The circuitry in the GDC uses three main elements: the Pattern register, the Mask register, and the 16-bit Logic Unit. The Pattern register holds the data pattern to be moved into memory. It is loaded by the WDAT command or, during drawing, from the parameter RAM. The Mask register contents determine which bits of the read data will be modified. Based on the contents of these registers, the Logic Unit performs the selected operations of REPLACE, COMPLEMENT, SET, or CLEAR on the data read from display memory.

The Pattern register contents are ANDed with the Mask register contents to enable the actual modification of the memory read data, on a bit-by-bit basis. For graphics drawing, one bit at a time from the Pattern register is combined with the Mask. When ANDed with the bit set to a 1 in the Mask register, the proper single pixel is modified by the Logic Unit. For the next pixel in the figure, the next bit in the Pattern register is selected and the Mask register bit is moved to identify the pixel's location within the word. The Execution word address pointer register, EAD, is also adjusted as required to address the word containing the next pixel.

In character mode, all of the bits in the Pattern register are used in parallel to form the respective bits of the modify data word. Since the bits of the character code word are used in parallel, unlike the one-bit-at-a-time graphics drawing process, this facility allows any or all of the bits in a memory word to be modified in one RMW memory cycle. The Mask register must be loaded with 1s in the positions where modification is to be permitted.

The Mask register can be loaded in either of two ways. In graphics mode, the CURS command contains a four-bit dAD field to specify the dot address. The command processor converts this parameter into the one-of-16 format used in the Mask register for figure drawing. A full 16 bits can be loaded into the Mask register using the MASK command. In addition to the character mode use mentioned above, the 16-bit MASK load is convenient in graphics mode when all of the pixels of a word are to be set to the same value.

The Logic Unit combines the data read from display memory, the Pattern Register, and the Mask register to generate the data to be written back into display memory. Any one of four operations can be selected: REPLACE, COMPLEMENT, CLEAR or SET. In each case, if the respective Mask bit is 0, that particular bit of the read data is returned to memory unmodified. If the Mask bit is 1, the modification is enabled. With the REPLACE operation, the modify data simply takes the place of the read data for modification enabled bits. For the other three operations, a 0 in the modify data allows the read data bit to be returned to memory. A 1 value causes the specified operation to be performed in the bit positions with set Mask bits.

Figure Drawing

The GDC draws graphics figures at the rate of one pixel per read-modify-write (RMW) display memory cycle. These cycles take four clock periods to complete. At a clock frequency of 5 MHz, this is equal to 800 ns. During the RMW cycle the GDC simultaneously calculates the address and position of the next pixel to be drawn.

The graphics figure drawing process depends on the display memory addressing structure. Groups of 16 horizontally adjacent pixels form the 16-bit words

which are handled by the GDC. Display memory is organized as a linearly addressed space of these words. Addressing of individual pixels is handled by the GDC's internal RMW logic.

During the drawing process, the GDC finds the next pixel of the figure which is one of the eight nearest neighbors of the last pixel drawn. The GDC assigns each of these eight directions a number from 0 to 7, starting with straight down and proceeding counterclockwise.

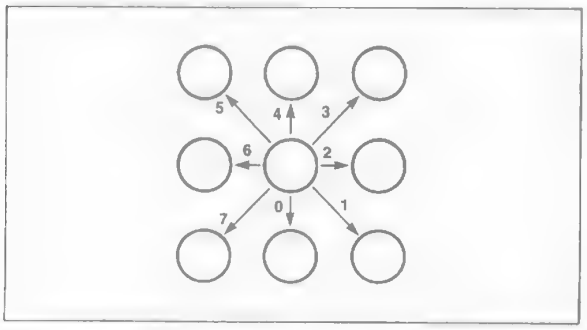

Figure 7. Drawing Directions

Figure drawing requires the proper manipulation of the address and the pixel bit position according to the drawing direction to determine the next pixel of the figure. To move to the word above or below the current one, it is necessary to subtract or add the number of words per line in display memory. This parameter is called the pitch. To move to the word to either side, the Execute word address cursor, EAD, must be incremented or decremented as the dot address pointer bit reaches the LSB or the MSB of the Mask register. To move to a pixel within the same word, it is necessary to rotate the dot address pointer register to the right or left.

Figure 8 summarizes these operations for each direction.

Whole word drawing is useful for filling areas in memory with a single value. By setting the Mask register to all 1s with the MASK command, both the LSB and MSB of the dAD will always be 1, so that the EAD value will be incremented or decremented for each cycle regardless of direction. One RMW cycle will be able to effect all 16 bits of the word for any drawing type. One bit in the Pattern register is used per RMW cycle to write all the bits of the word to the same value. The next Pattern bit is used for the word, etc.

```
DIR   ADDRESS OPERATION
000   CAD = CAD + P
001   CAD = CAD - P
      IF dAD (LSB) = 1 THEN CAD = CAD - 1
      dAD = RR( dAD )
010   IF dAD (LSB) = 1 THEN CAD = CAD - 1
      dAD = RR( dAD )
011   CAD = CAD - P
      IF dAD (LSB) = 1 THEN CAD = CAD + 1
      dAD = RR( dAD )
100   CAD = CAD + P
101   CAD = CAD - P
      IF dAD (MSB) = 1 THEN CAD = CAD - 1
      dAD = LR( dAD )
110   IF dAD (MSB) = 1 THEN CAD = CAD - 1
      dAD = LR( dAD )
111   CAD = CAD - P
      IF dAD (MSB) = 1 THEN CAD = CAD - 1
      dAD = LR( dAD )

WHERE
    P - PITCH, LR = LEFT ROTATE, RR = RIGHT ROTATE
  CAD - CURSOR ADDRESS
  dAD - DOT ADDRESS
  LSB - LEAST SIGNIFICANT BIT
  MSB - MOST SIGNIFICANT BIT
```

Figure 8. Address Calculation Details

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For the various figures, the effect of the initial direction upon the resulting drawing is shown below:

Note that during line drawing, the angle of the line may be anywhere within the shaded octant defined by the DIR value. Arc drawing starts in the direction initially specified by the DIR value and veers into an arc as drawing proceeds. An arc may be up to 45 degrees in length. DMA transfers are done on word boundaries only, and follow the arrows indicated in the table to find successive word addresses. The slanted paths for DMA transfers indicate the GDC changing boh the X and Y components of the word address when moving to the next word. It does not follow a 45 degree diagonal path by pixels.

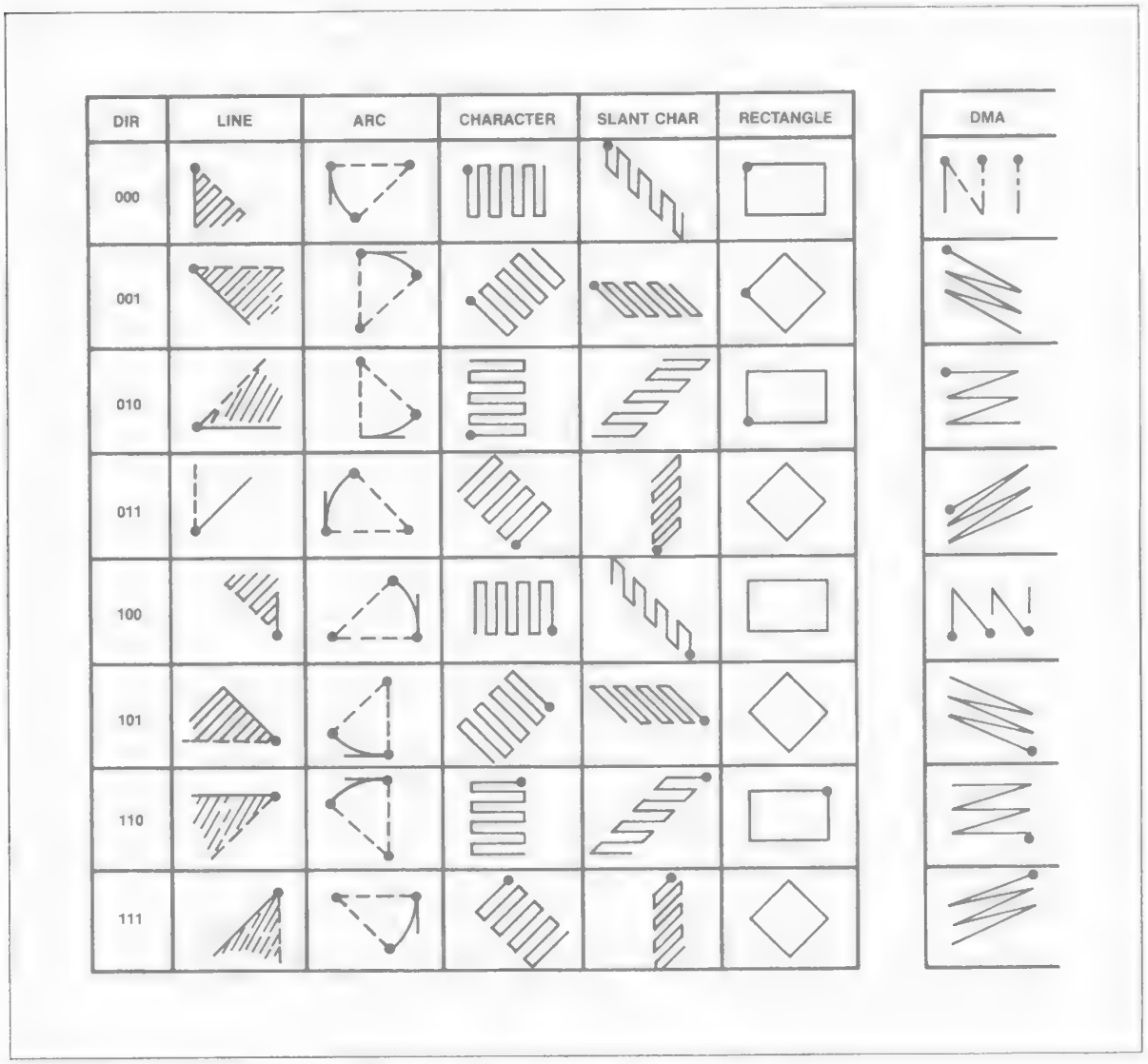

Figure 9. Effect of the Direction Parameter

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Drawing Parameters

In preparation for graphics figure drawing, the GDC's Drawing Processor needs the figure type, direction and drawing parameters, the starting pixel address, and the pattern from the microprocessor. Once these are in place within the GDC, the Figure Draw command, FIGD, initiates the drawing operation. From that point on, the system microprocessor is not involved in the drawing process. The GDC Drawing Processor coordinates the RMW circuitry and address registers to draw the specified figure pixel by pixel.

The algorithms used by the processor for figure drawing are designed to optimize its drawing speed. To this end, the specific details about the figure to be drawn are reduced by the microprocessor to a form conducive to high-speed address calculations within the GDC. In this way the repetitive, pixel-by-pixel calculations can be done quickly, thereby minimizing the overall figure drawing time. Figure 10 summarizes the parameters.

Graphics Character Drawing

Graphics characters can be drawn into display memory pixel-by-pixel. The up to 8-by-8 character is loaded into the GDC's parameter RAM by the system microprocessor. Consequently, there are no limitations on the character set used. By varying the drawing parameters and drawing direction, numerous drawing options are available. In area fill applications, a character can be written into display memory as many times as desired without reloading the parameter RAM.

Once the parameter RAM has been loaded with up to eight graphics character bytes by the appropriate PRAM command, the GCHRD command can be used to draw the bytes into display memory starting at the cursor. The zoom magnification factor for writing, set by the zoom command, controls the size of the character written into the display memory in integer multiples of 1 through 16. The bit values in the PRAM are repeated horizontally and vertically the number of times specified by the zoom factor.

The movement of these PRAM bytes to the display memory is controlled by the parameters of the FIGS command. Based on the specified height and width of the area to be drawn, the parameter RAM is scanned to fill the required area.

For an 8-by-8 graphics character, the first pixel drawn uses the LSB of RA-15, the second pixel uses bit 1 of RA-15, and so on, until the MSB of RA-15 is reached.

The GDC jumps to the corresponding bit in RA-14 to continue the drawing. The progression then advances toward the LSB of RA-14. This snaking sequence is continued for the other 6 PRAM bytes. This progression matches the sequence of display memory addresses calculated by the drawing processor. If the area is narrower than 8 pixels wide, the snaking will advance to the next PRAM byte before the MSB is reached. If the area is less than 8 lines high, fewer bytes in the parameter RAM will be scanned. If the area is larger than 8 by 8, the GDC will repeat the contents of the parameter RAM in two dimensions, as required to fill the area with the 8-by-8 mosaic. (Fractions of the 8-by-8 pattern will be used to fill areas which are not multiples of 8 by 8.)

DRAWING TYPE	DC	D	D2	D1	DM
INITIAL VALUE*	0	B	B	1	1
LINE	ΔI	$2\ \Delta D\|-\|\Delta I\|$	$2(\Delta D-\Delta I)$	$2\ \Delta D$	—
ARC**	$r \sin\phi\uparrow$	$r-1$	$2(r-1)$	-1	$r\sin\theta\downarrow$
RECTANGLE	3	$A-1$	$B-1$	-1	$A-1$
AREA FILL	$B-1$	A	A	—	—
GRAPHIC CHARACTER***	$B-1$	A	A	—	—
READ & WRITE DATA	$W-1$	—	—	—	—
DMAW	$D-1$	$C-1$	—	—	—
DMAR	$D-1$	$C-1$	$(C-1)/2\not\leq$	—	—

* INITIAL VALUES FOR THE VARIOUS PARAMETERS ARE LOADED DURING THE HANDLING OF THE FIGS OP CODE BYTE.
** CIRCLES ARE DRAWN WITH 8 ARCS, EACH OF WHICH SPAN 45°, SO THAT SIN $\phi = 1/\sqrt{2}$ AND SIN $\theta = 0$.
*** GRAPHIC CHARACTERS ARE A SPECIAL CASE OF BIT-MAP AREA FILLING IN WHICH B AND A ≤ 8. IF A = 8 THERE IS NO NEED TO LOAD D AND D2.

WHERE:
−1 = ALL ONES VALUE.
ALL NUMBERS ARE SHOWN IN BASE 10 FOR CONVENIENCE. THE GDC ACCEPTS BASE 2 NUMBERS (2S COMPLEMENT NOTATION WHERE APPROPRIATE).

- — = NO PARAMETER BYTES SENT TO GDC FOR THIS PARAMETER.
- ΔI = THE LARGER OF ΔX OR ΔY. (DEPENDENT AXIS)
- ΔD = THE SMALLER OF ΔX OR ΔY. (INDEPENDENT AXIS)
- r = RADIUS AT CURVATURE, IN PIXELS.
- ϕ = ANGLE FROM MAJOR AXIS TO END AT THE ARC. $\phi \leq 45°$.
- θ = ANGLE FROM MAJOR AXIS TO START AT THE ARC. $\theta \leq 45°$.
- $\uparrow$ = ROUND UP TO THE NEXT HIGHER INTEGER.
- $\downarrow$ = ROUND DOWN TO THE NEXT LOWER INTEGER.
- A = NUMBER OF PIXELS IN THE INITIALLY SPECIFIED DIRECTION.
- B = NUMBER OF PIXELS IN THE DIRECTION AT RIGHT ANGLES TO THE INITIALLY SPECIFIED DIRECTION.
- W = NUMBER OF WORDS TO BE ACCESSED.
- C = NUMBER OF BYTES TO BE TRANSFERRED IN THE INITIALLY SPECIFIED DIRECTION. (TWO BYTES PER WORD IF WORD TRANSFER MODE IS SELECTED.)
- D = NUMBER OF WORDS TO BE ACCESSED IN THE DIRECTION AT RIGHT ANGLES TO THE INITIALLY SPECIFIED DIRECTION.
- DC = DRAWING COUNT PARAMETER WHICH IS ONE LESS THAN THE NUMBER OF RMW CYCLES TO BE EXECUTED.
- DM = DOTS MASKED FROM DRAWING DURING ARC DRAWING.
- $\not\leq$ = NEEDED ONLY FOR WORD READS.

Figure 10. Drawing Parameter Details

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Parameter RAM Contents RAM Address RA 0 to 15

The parameters stored in the parameter RAM, PRAM, are available for the GDC to refer to repeatedly during figure drawing and raster-scanning. In each mode of operation the values in the PRAM are interpreted by the GDC in a predetermined fashion. The host microprocessor must load the appropriate parameters into the proper PRAM locations. PRAM loading command allows the host to write into any location of the PRAM and transfer as many bytes as desired. In this way any stored parameter byte or bytes may be changed without influencing the other bytes.

The PRAM stores two types of information. For specifying the details of the display area partitions, blocks of four bytes are used. The four parameters stored in each block include the starting address in display memory of each display area, and its length. In addition, there are two mode bits for each area which specify whether the area is a bit-mapped graphics area or a coded character area, and whether a 16-bit or a 32-bit wide display cycle is to be used for that area.

The other use for the PRAM contents is to supply the pattern for figure drawing when in a bit-mapped graphics area or mode. In these situations, PRAM bytes 8 through 16 are reserved for this patterning information. For line, arc, and rectangle drawing (linear figures) locations 8 and 9 are loaded into the Pattern Register to allow the GDC to draw dotted, dashed, etc. lines. For area filling and graphics bit-mapped character drawing locations 8 through 15 are referenced for the pattern or character to be drawn.

Details of the bit assignments are shown on the following pages for the various modes of operation.

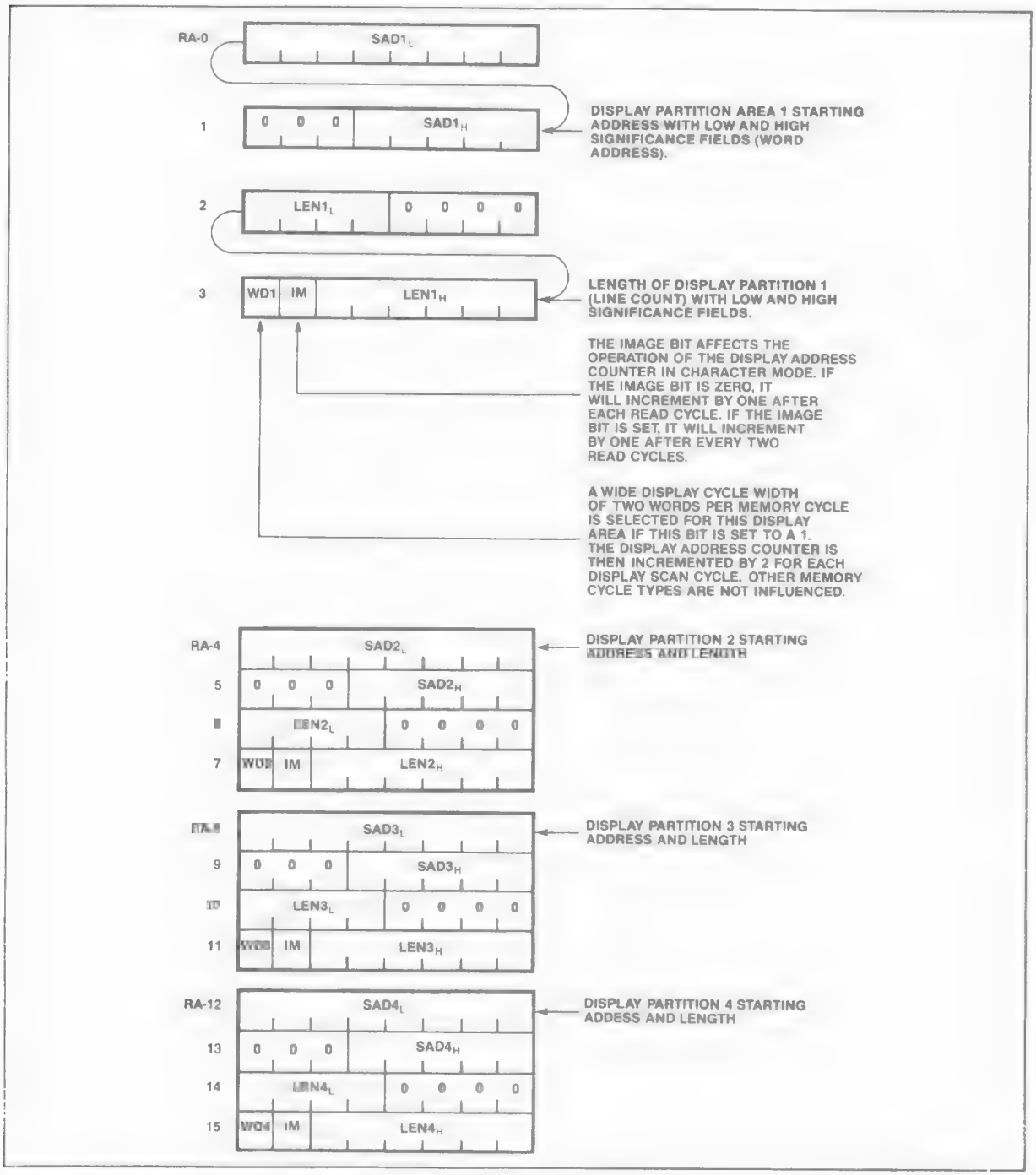

Figure 11. Character Mode

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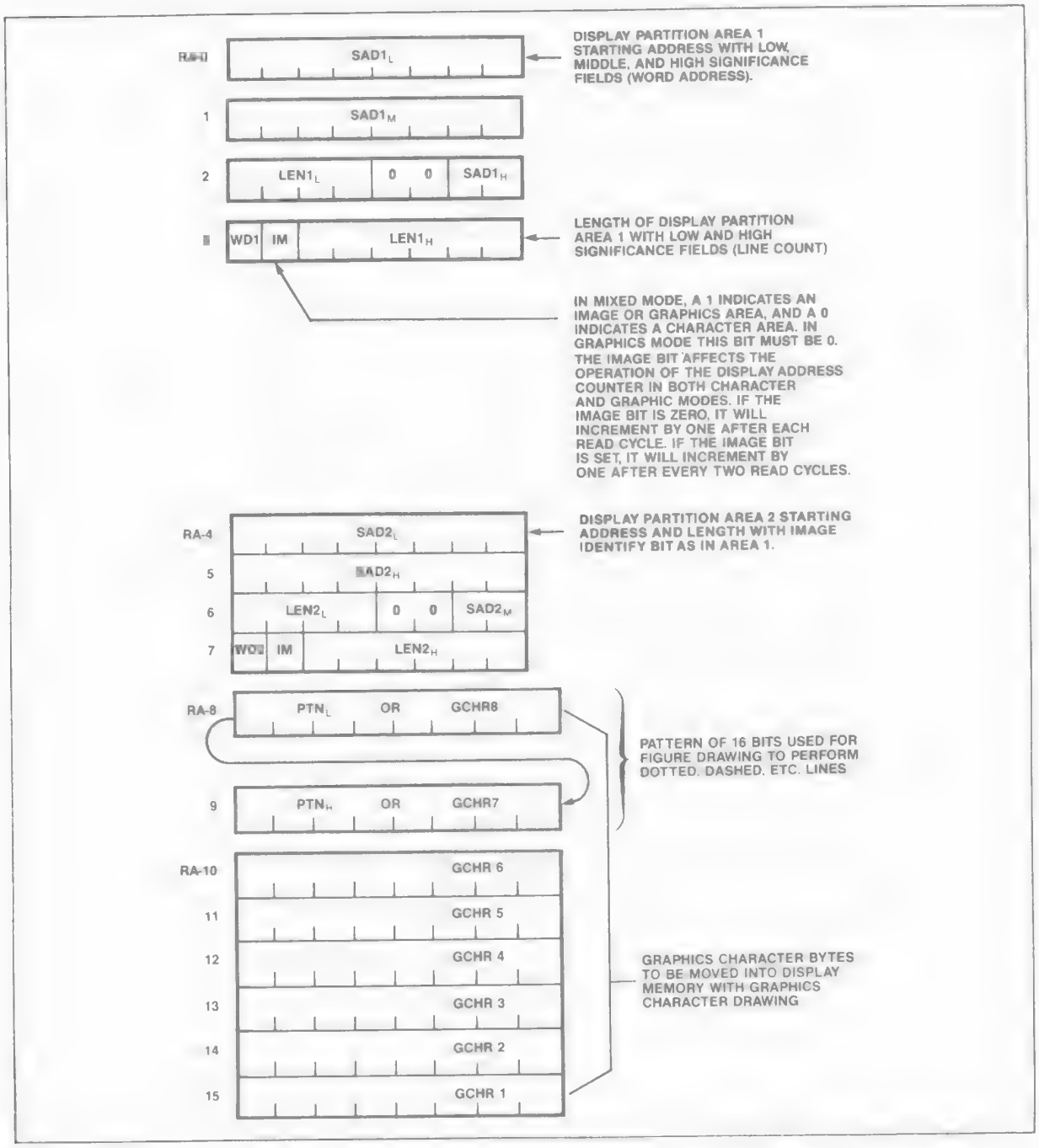

Figure 12. Graphics and Mixed Graphics and Character Modes

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RESET:	0	0	0	0	0	0	0	0	WDAT:	0	0	1	TYPE	0	MOD	
SYNC:	0	0	0	0	1	1	1	DE	MASK:	0	1	0	0	1	0	1	0
VSYNC:	0	1	1	0	1	1	1	M	FIGS:	0	1	0	0	1	1	0	0
CCHAR:	0	1	0	0	1	0	1	1	FIGD:	0	1	1	0	1	1	0	0
START:	0	1	1	0	1	0	1	1	GCHRD:	0	1	1	0	1	0	0	0
BCTRL:	0	0	0	0	1	1	0	DE	RDAT:	1	0	1	TYPE	0	MOD	
ZOOM:	0	1	0	0	0	1	1	0	CURD:	1	1	1	0	0	0	0	0
CURS:	0	1	0	0	1	0	0	1	LPRD:	1	1	0	0	0	0	0	0
PRAM:	0	1	1	1	SA				DMAR:	1	0	1	TYPE	1	MOD	
PITCH:	0	1	0	0	0	1	1	1	DMAW:	0	0	1	TYPE	1	MOD	

Figure 13. Command Bytes Summary

VIDEO CONTROL COMMANDS

RESET:	0	0	0	0	0	0	0	0	BLANK THE DISPLAY, ENTER IDLE MODE, AND INITIALIZE WITHIN THE GDC: —FIFO —COMMAND PROCESSOR —INTERNAL COUNTERS

Figure 14. Reset Command

RESET COMMAND

This command can be executed at any time and does not modify any of the parameters already loaded into the GDC.

If followed by parameter bytes, this command also sets the sync generator parameters as described below. Idle mode is exited with the START command.

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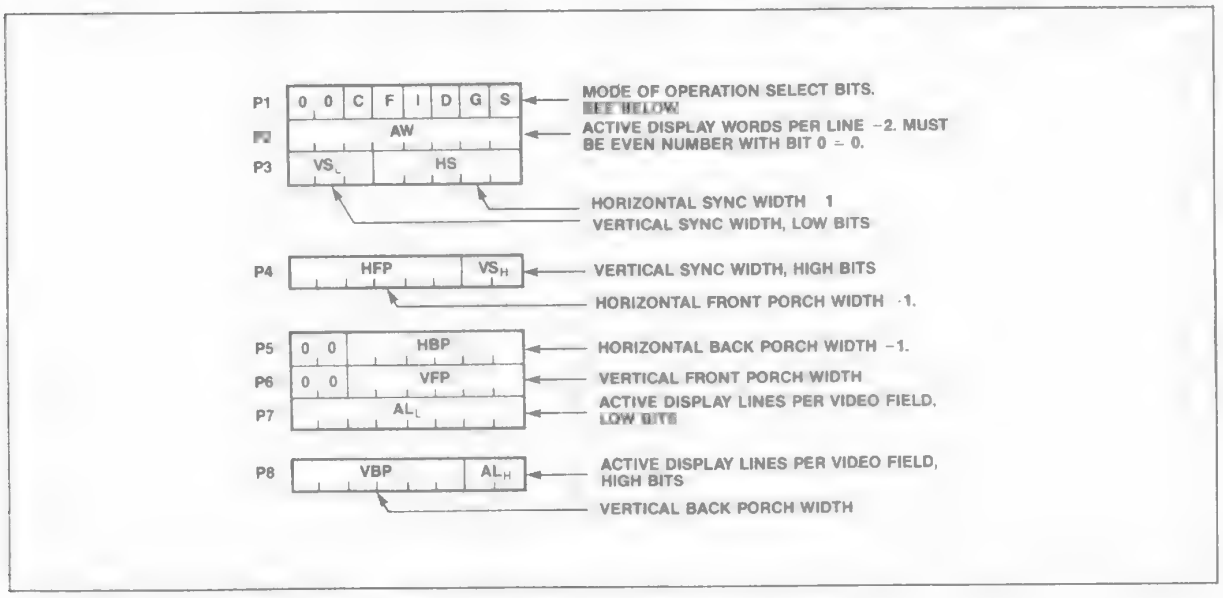

Figure 15. Optional Reset Parameters

In graphics mode, a word is a group of 16 pixels. In character mode, a word is one character code and its attributes, if any.

The number of active words per line must be an even number from 2 to 256.

An all-zero parameter value selects a count equal to 2^n where n = number of bits in the parameter field for vertical parameters.

All horizontal widths are counted in display words. All vertical intervals are counted in lines.

SYNC Generator Period Constraints

HORIZONTAL BACK PORCH CONSTRAINTS

1. In general:
   HBP ≥ 3 Display Word Cycles (6 clock cycles).
2. If the IMAGE or WD modes change within one video field:
   HBP ≥ 5 Display Word Cycles (10 clock cycles).

HORIZONTAL FRONT PORCH CONSTRAINTS

1. If the display ZOOM function is used at other than 1X:
   HFP ≥ 2 Display Word Cycles (4 clock cycles).
2. If the GDC is used in the video sync Slave mode:
   HFP ≥ 4 Display Word Cycles (8 clock cycles).
3. If the Light Pen is used:
   HFP ≥ 6 Display Word Cycles (12 clock cycles).

HORIZONTAL SYNC CONSTRAINTS

1. If Interlaced display mode is used:
   HS ≥ 3 Display Word Cycles (6 clock cycles).

Repeat Field Framing:	2 Field Sequence with ½ line offset between otherwise identical fields.
Interlaced Framing:	2 Field Sequence with ½ line offset. Each field displays alternate lines.
Noninterlaced Framing:	1 field brings all of the information to the screen.

Total scanned lines in interlace mode is odd. The sum of VFP + VS + VBP + AL should equal one less than the desired odd number of lines.

Dynamic RAM refresh is important when high display zoom factors or DMA are used in such a way that not all of the rows in the RAMs are regularly accessed during display raster generation and for otherwise inactive display memory.

Access to display memory can be limited to retrace blanking intervals only, so that no disruptions of the image are seen on the screen.

C G	DISPLAY MODE
0 0	MIXED GRAPHICS & CHARACTER
0 1	GRAPHICS MODE
1 0	CHARACTER MODE
1 1	INVALID

I S	VIDEO FRAMING
0 0	NONINTERLACED
0 1	INVALID
1 0	INTERLACED REPEAT FIELD FOR CHARACTER DISPLAYS
1 1	INTERLACED

D	DYNAMIC RAM REFRESH CYCLES ENABLE
0	NO REFRESH—STATIC RAM
1	REFRESH—DYNAMIC RAM

F	DRAWING TIME WINDOW
0	DRAWING DURING ACTIVE DISPLAY TIME AND RETRACE BLANKING
1	DRAWING ONLY DURING RETRACE BLANKING

Figure 16. Modes of Operation Bits

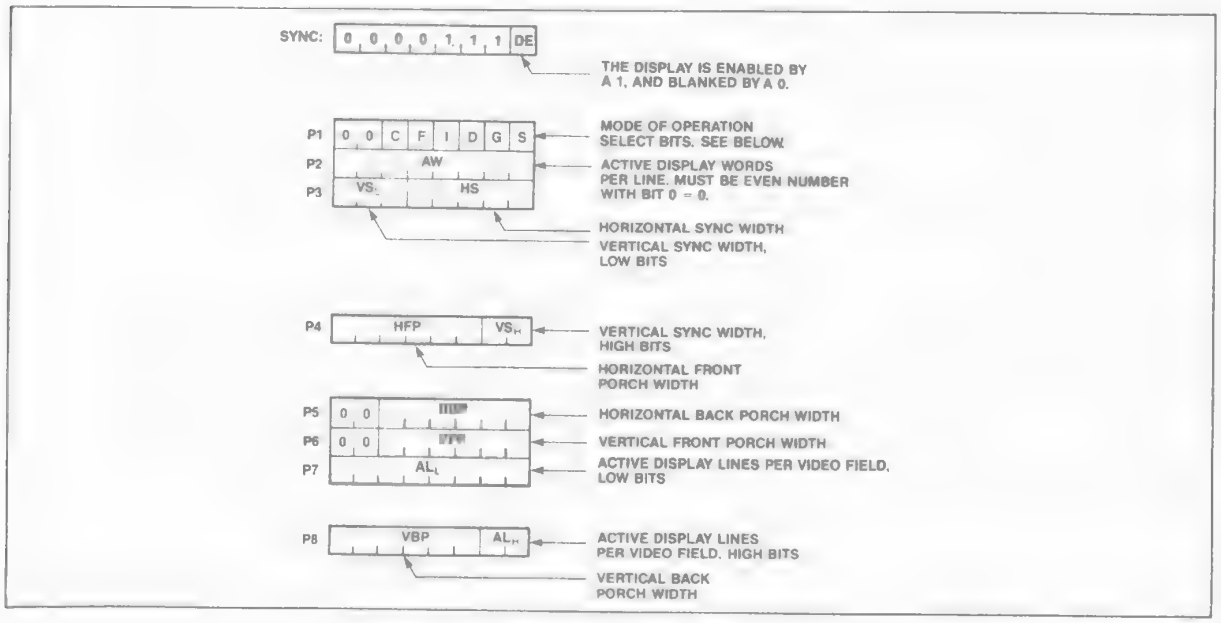

Figure 17. SYNC Format Specify Command

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SYNC FORMAT SPECIFY COMMAND

This command loads parameters into the sync generator. The various parameter fields and bits are identical to those at the RESET command. The GDC is not reset nor does it enter idle mode.

Vertical Sync Mode Command

When using two or more GDCs to contribute to one image, one GDC is defined as the master sync generator, and the others operate as its slaves. The VSYNC pins of all GDCs are connected together.

Slave Mode Operation

A few considerations should be observed when synchronizing two or more GDCs to generate overlayed video via the VSYNC INPUT/OUTPUT pin. As mentioned above, the Horizontal Front Porch (HFP) must be 4 or more display cycles wide. This is equivalent to eight or more clock cycles. This gives the slave GDCs time to initialize their internal video sync generators to the proper point in the video field to match the incoming vertical sync pulse (VSYNC). This resetting of the generator occurs just after the end of the incoming VSYNC pulse, during the HFP interval. Enough time during HFP is required to allow the slave GDC to complete the operation before the start of the HSYNC interval.

Once the GDCs are initialized and set up as Master and Slaves, they must be given time to synchronize. It is a good idea to watch the VSYNC status bit of the Master GDC and wait until after one or more VSYNC pulses have been generated before the display process is started. The START command will begin the active display of data and will end the video synchronization process, so be sure there has been at least one VSYNC pulse generated for the Slaves to synchronize to.

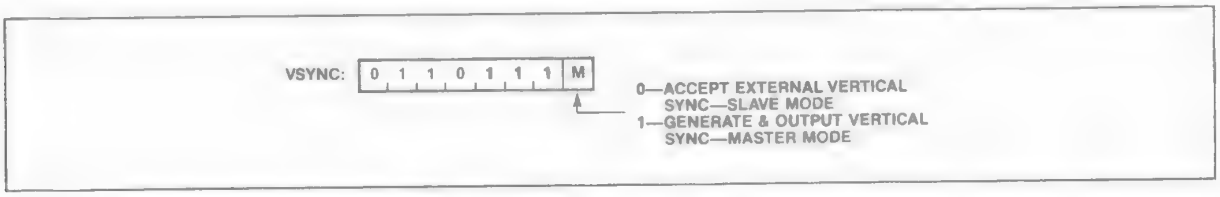

Figure 18. Vertical Sync Mode Command

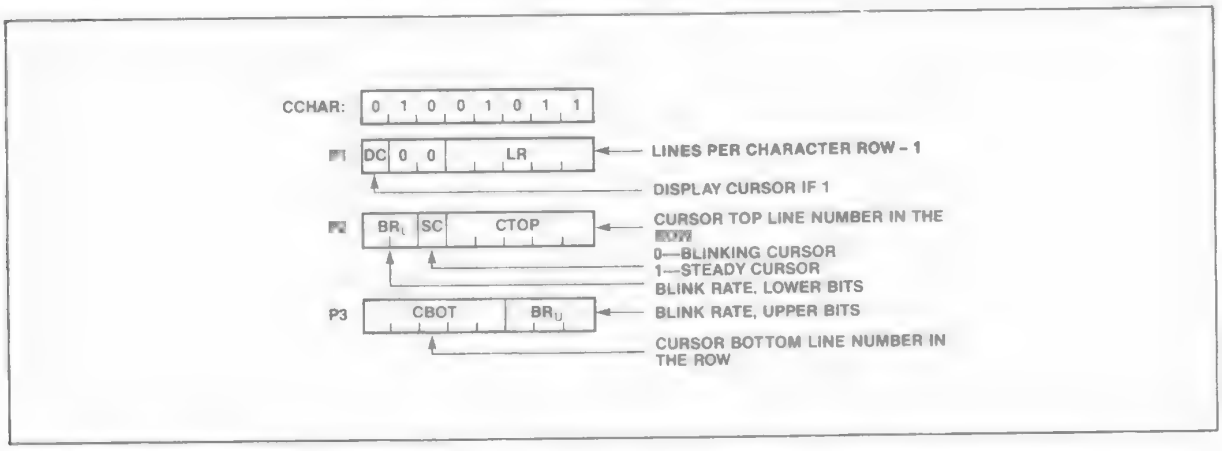

Figure 19. Cursor & Character Characteristics Command

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Cursor and Character Characteristics Command

In graphics mode, LR should be set to 0. The blink rate parameter controls both the cursor and attribute blink rates. The cursor blink-on-time = blink-off time = 2 x BR (video frames). The attribute blink rate is always ½ the cursor rate but with a ¾ on-¼ off duty cycle.

Zoom Factors Specify Command

Zoom magnification factors of 1 through 16 are available using codes 0 through 15, respectively.

Cursor Position Specify Command

In character mode, the third parameter byte is not needed. The cursor is displayed for the word time in which the display scan address (DAD) equals the cursor address. In graphics mode, the cursor word address specifies the word containing the starting pixel of the drawing; the dot address value specifies the pixel within that word.

Parameter RAM Load Command

From the starting address, SA, any number of bytes may be loaded into the parameter RAM at incrementing addresses, up to location 15. The sequence of parameter bytes is terminated by the next command byte entered into the FIFO. The parameter RAM stores 16 bytes of information in predefined locations which differ for graphics and character modes. See the parameter RAM discussion for bit assignments.

Pitch Specification Command

This value is used during drawing by the drawing processor to find the word directly above or below the current word, and during display to find the start of the next line.

The Pitch parameter (width of display memory) is set by two different commands. In addition to the PITCH command, the RESET (or SYNC) command also sets the pitch value. The "active words per line" parameter, which specifies the width of the raster-scan display, also sets the Pitch of the display memory. In situations in which these two values are equal there is no need to execute a PITCH command.

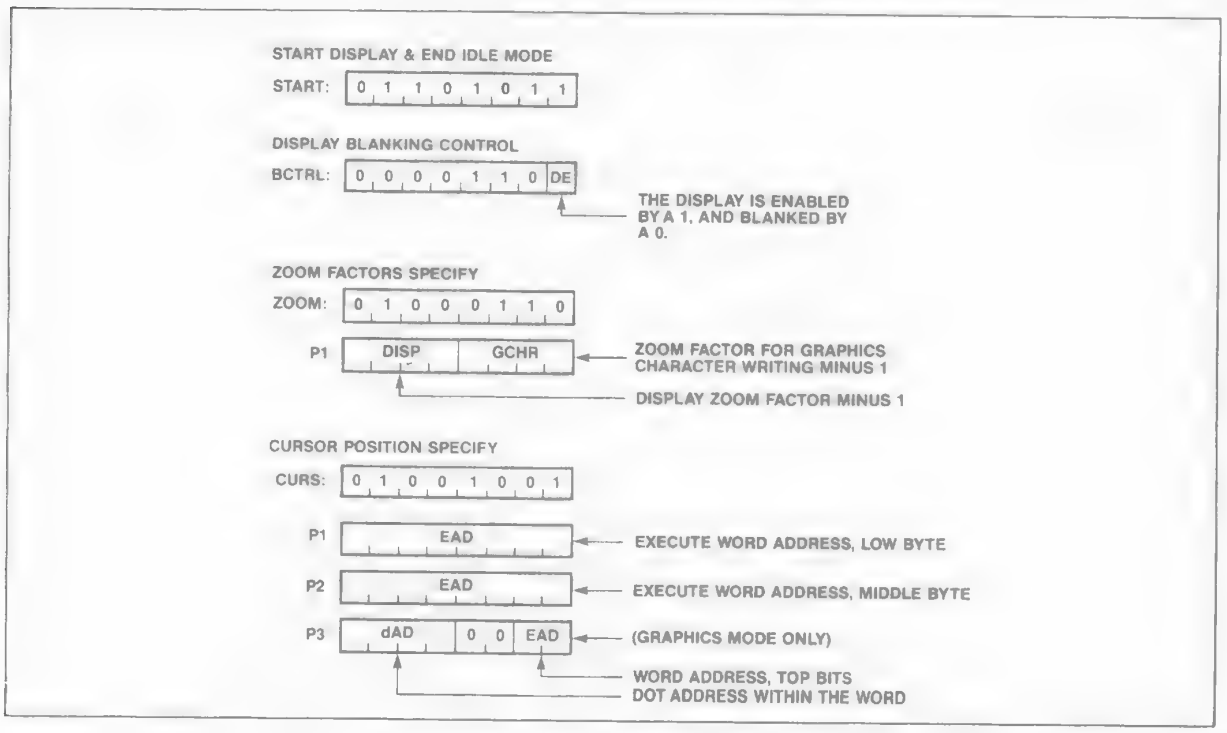

Figure 20. Display Control Commands

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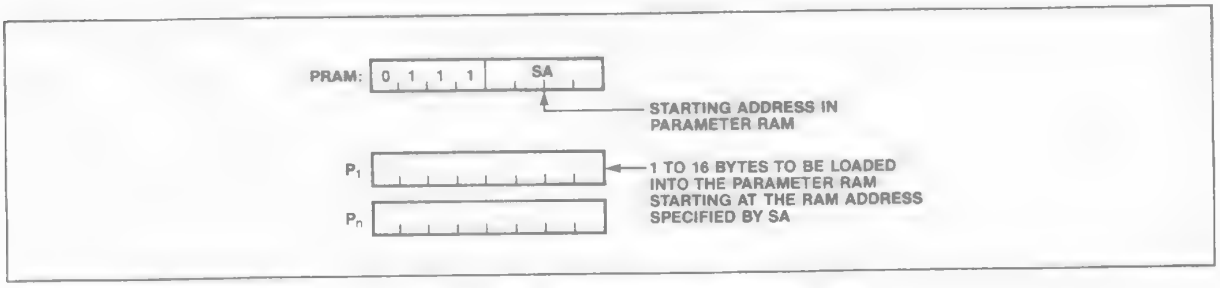


Figure 21. Parameter RAM Load

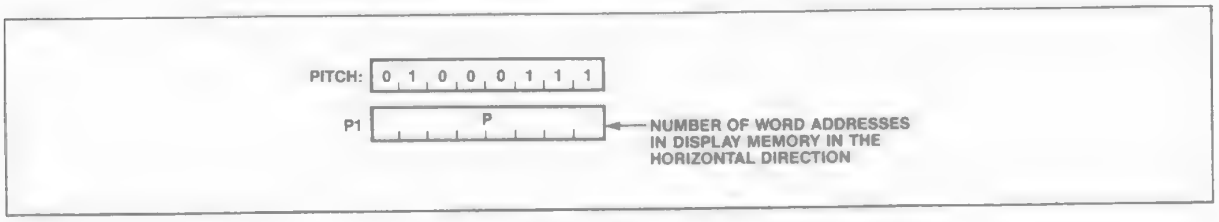


Figure 22. Pitch Specification

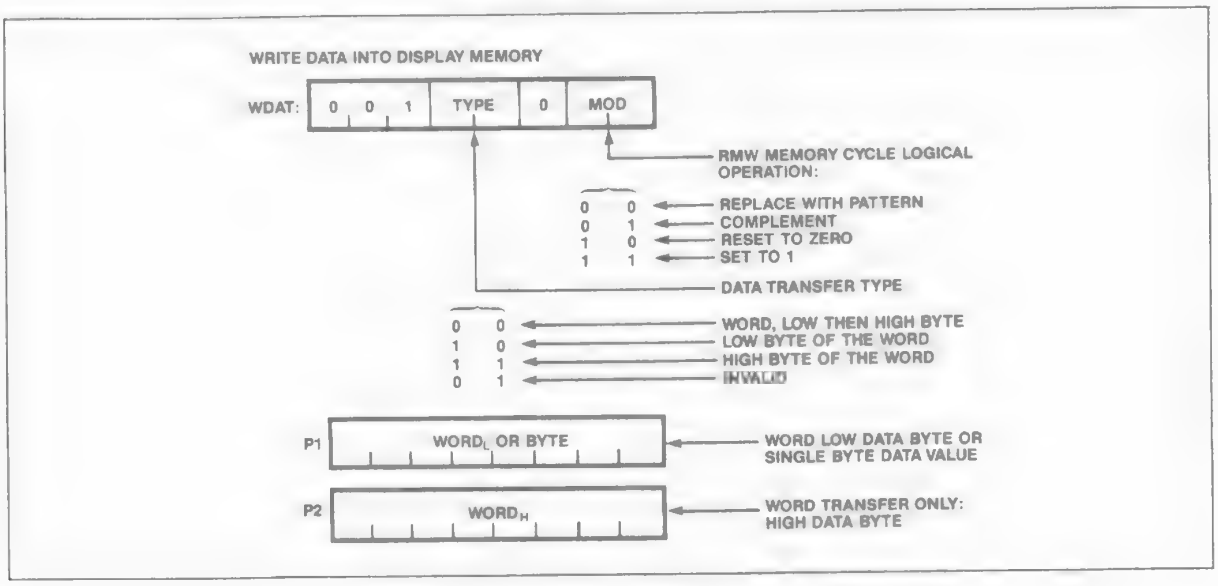


Figure 23. Drawing Control Commands

Write Data Command

Upon receiving a set of parameters (two bytes for a word transfer, one for a byte transfer), one RMW cycle into Video Memory is done at the address pointed to by the cursor EAD. The EAD pointer is advanced to the next word, according to the previously specified direction. More parameters can then be accepted.

For byte writes, the unspecified byte is treated as all zeros during the RMW memory cycle.

In graphics bit-map situations, only the LSB of the WDAT parameter bytes is used as the pattern in the RMW operations. Therefore it is possible to have only an all ones or all zeros pattern. In coded character applications all the bits of the WDAT parameters are used to establish the drawing pattern.

The WDAT command operates differently from the other commands which initiate RMW cycle activity. It requires parameters to set up the Pattern register while the other commands use the stored values in the parameter RAM. Like all of these commands, the

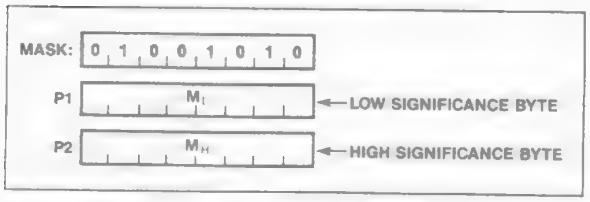
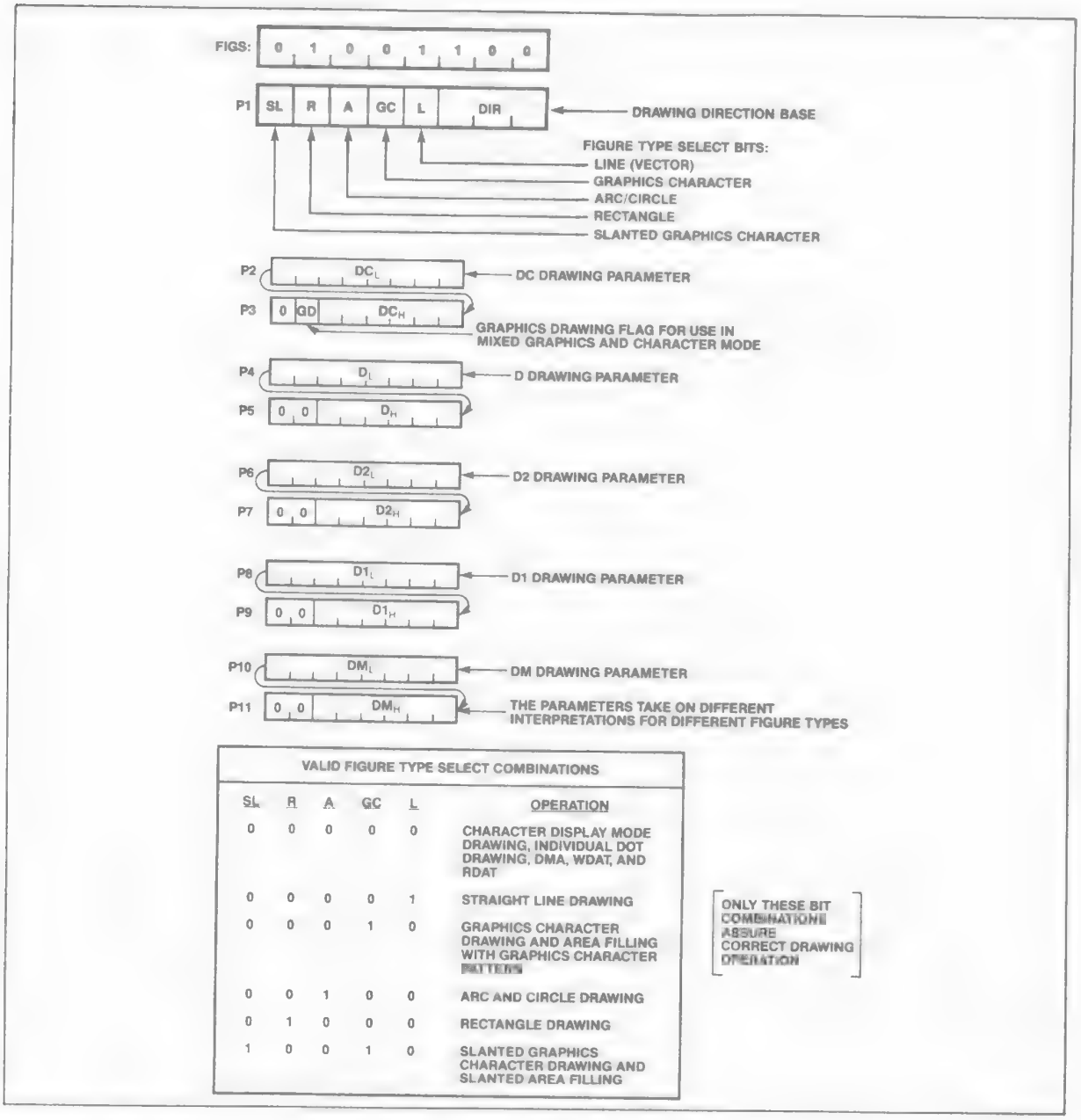


Figure 24. Mask Register Load

WDAT command must be preceeded by a FIGS command and its parameters. Only the first three parameters need be given following the FIGS opcode, to set up the type of drawing, the DIR direction, and the DC value. The DC parameter +1 will be the number of RMW cycles done by the GDC with the first set of WDAT parameters. Additional sets of WDAT parameters will see a DC value of 0 which will cause only one RMW cycle to be executed.



VALID FIGURE TYPE SELECT COMBINATIONS

SL	R	A	GC	L	OPERATION
0	0	0	0	0	CHARACTER DISPLAY MODE DRAWING, INDIVIDUAL DOT DRAWING, DMA, WDAT, AND RDAT
0	0	0	0	1	STRAIGHT LINE DRAWING
0	0	0	1	0	GRAPHICS CHARACTER DRAWING AND AREA FILLING WITH GRAPHICS CHARACTER PATTERNS
0	0	1	0	0	ARC AND CIRCLE DRAWING
0	1	0	0	0	RECTANGLE DRAWING
1	0	0	1	0	SLANTED GRAPHICS CHARACTER DRAWING AND SLANTED AREA FILLING

ONLY THESE BIT COMBINATIONS ASSURE CORRECT DRAWING OPERATION

Figure 25. Figure Drawing Parameters Specify

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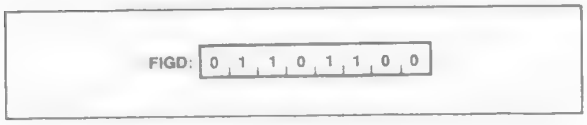

Figure 26. Figure Draw Start

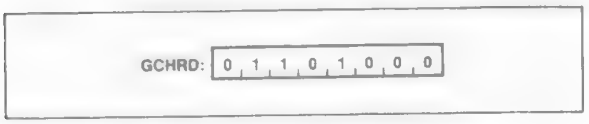

Figure 27. Graphics Character Draw and Area Filling Start

Mask Register Load Command

This command sets the value of the 16-bit Mask register of the figure drawing processor. The Mask register controls which bits can be modified in the display memory during a read-modify-write cycle.

The Mask register is loaded both by the MASK command and the third parameter byte of the CURS command. The MASK command accepts two parameter bytes to load a 16-bit value into the MASK register. All 16 bits can be individually one or zero, under program control. The CURS command on the other hand, puts a "1 to 16" pattern into the Mask register based on the value of the Dot Address value, dAD. If normal single-pixel-at-a-time graphics figure drawing is desired, there is no need to do a MASK command at all since the CURS command will set up the proper pattern to address the proper pixels as drawing progresses. For coded character DMA, and screen setting and clearing operations using the WDAT command, the MASK command should be used after the CURS command if its third parameter byte has been output.

Figure Draw Start Command

On execution of this instruction, the GDC loads the parameters from the parameter RAM into the drawing processor and starts the drawing process at the pixel pointed to by the cursor, EAD, and the dot address, dAD.

Graphics Char. Draw and Area Fill Start Command

Based on parameters loaded with the FIGS command, this command initiates the drawing of the graphics character or area filling pattern stored in Parameter RAM. Drawing begins at the address in display memory pointed to by the EAD and dAD values.

Read Data Command

Using the DIR and DC parameters of the FIGS command to establish direction and transfer count, multiple RMW cycles can be executed without specification of the cursor address after the initial load (DC = number of words or bytes).

As this instruction begins to execute, the FIFO buffer direction is reversed so that the data read from display memory can pass to the microprocessor. Any commands or parameters in the FIFO at this time will be lost. A command byte sent to the GDC will immediately reverse the buffer direction back to write mode, and all RDAT information not yet read from the FIFO will be lost. MOD should be set to 00.

Cursor Address Read Command

The Execute Address, EAD, points to the display memory word containing the pixel to be addressed.

The Dot Address, dAD, within the word is represented as a 1-of-16 code for graphics drawing operations.

Light Pen Address Read Command

The light pen address, LAD, corresponds to the display word address, DAD, at which the light pen input signal is detected and deglitched.

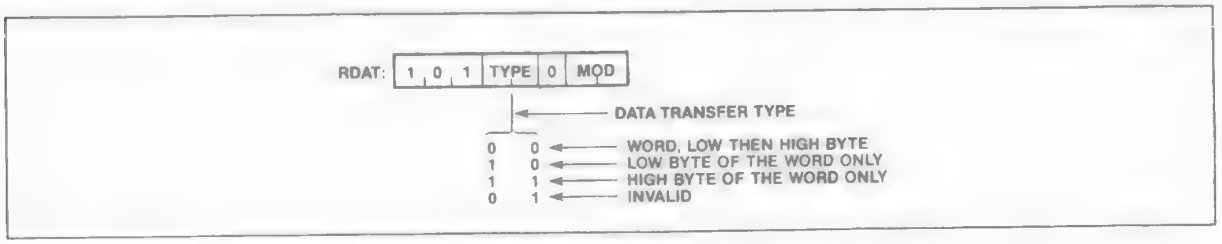

Figure 28. Read Data from Display Memory

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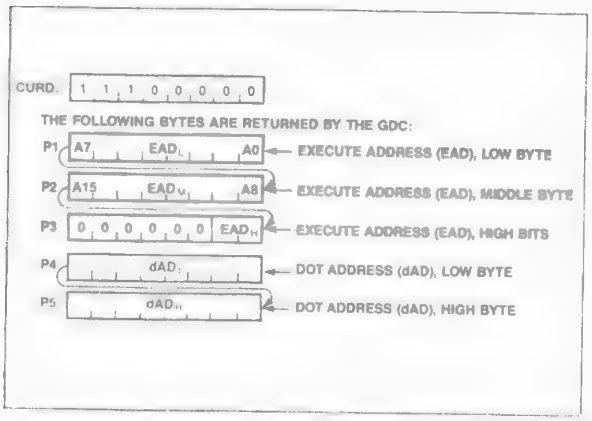

Figure 29. Cursor Address Read

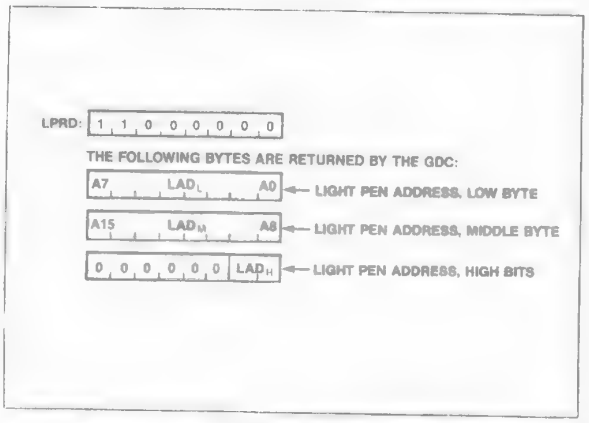

Figure 30. Light Pen Address Read

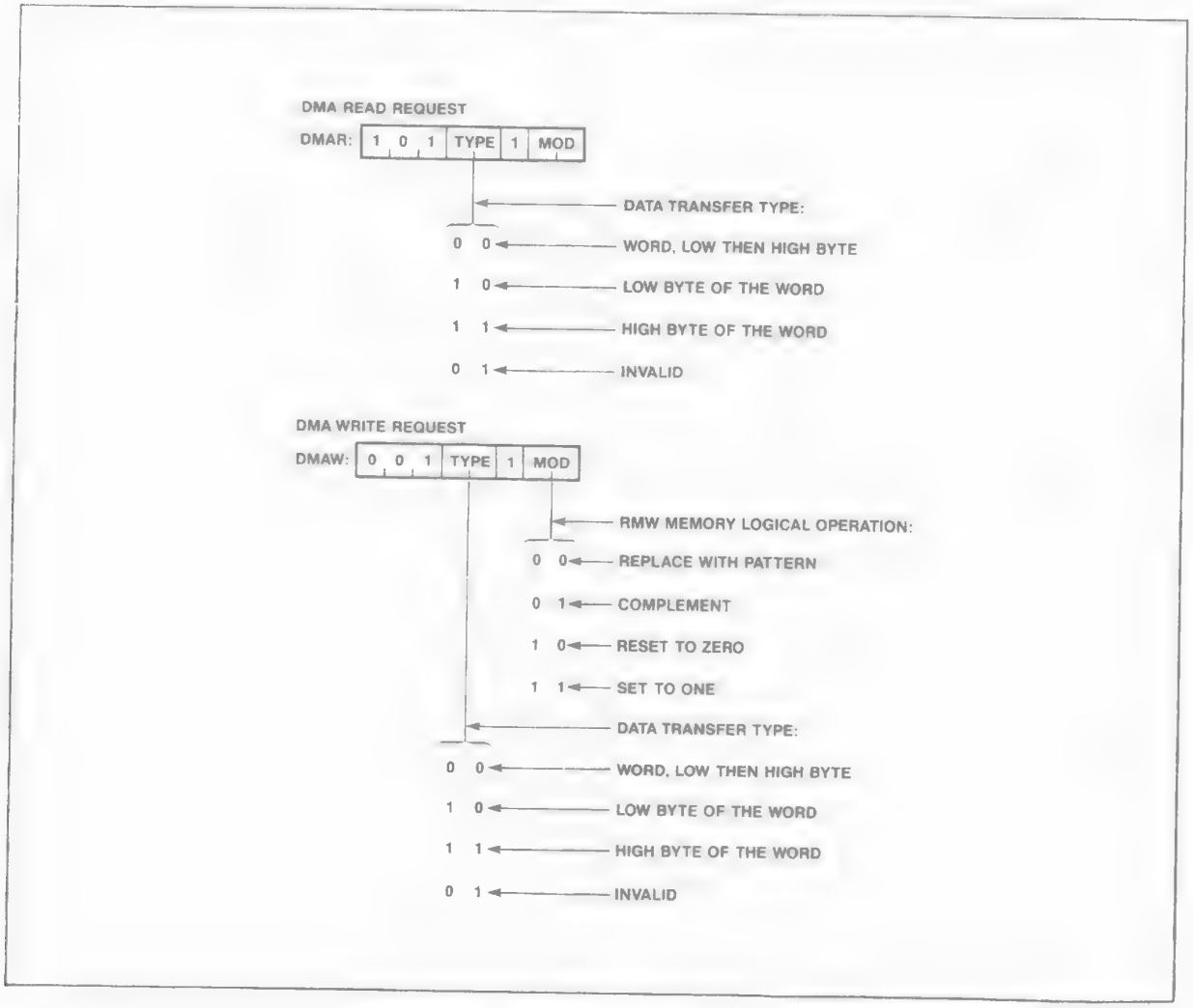

Figure 31. DMA Control Commands

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ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature Under Bias ..... 0°C to 70°C
Storage Temperature ..... −65°C to 150°C
Voltage on any Pin with Respect
to Ground ..... −0.5V to +7V
Power Dissipation ..... 1.5 Watt

**COMMENT: Exposing the device to stresses above those listed in Absolute Maximum Ratings could cause permanent damage. The device is not meant to be operated under conditions outside the limits described in the operational sections of this specification. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

DC CHARACTERISTICS

T_A = 0°C to 70° C; V_{CC} = 5V ± 10%; GND = 0V

Symbol	Parameter	Limits		Unit	Conditions
		Min.	Max.		
V_{IL}	Input Low Voltage	−0.5	0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2.2 mA
V_{OH}	Output High Voltage	2.4		V	I_{OH} = −400 μA
I_{OZ}	Output Leakage Current		±10	μA	V_{SS} + 0.45 ≤ V_I ≤ V_{CC}
I_{IL}	Input Leakage Current		±10	μA	V_{SS} ≤ V_I ≤ V_{CC}
V_{CL}	Clock Input Low Voltage	−0.5	0.6	V	
V_{CH}	Clock Input High Voltage	3.9	V_{CC} + 1.0	V	
I_{CC}	V_{CC} Supply Current		270	mA	Typical = 150 mA

CAPACITANCE

T_A = 25°C; V_{CC} = GND = 0V

Symbol	Parameter	Limits		Unit	Conditions
		Min.	Max.		
C_{IN}	Input Capacitance		10	pF	
C_{IO}	I/O Capacitance		20	pF	fc = 1 MHz
C_{OUT}	Output Capacitance		20	pF	V_1
C_O	Clock Input Capacitance		20	pF	(Unmeasured)=0V

A.C. CHARACTERISTICS (T_A = 0°C to +70°C, V_{SS} = 0V, V_{CC} = +5V ±10%)

DATA BUS READ CYCLE

Symbol	Parameter	82720		82720-1		Units	Test Conditions
		Min.	Max.	Min.	Max.		
T_{AR}	A_0 setup to $\overline{RD}$↓	0		0		ns	
T_{RA}	A_0 hold after $\overline{RD}$↑	0		0		ns	
T_{RR}	$\overline{RD}$ Pulse Width	T_{RD}+20		T_{RD}+20		ns	
T_{RD}	$\overline{RD}$↓ to Data Out Delay		120		80	ns	CL=50pF
T_{DF}	$\overline{RD}$↑ to Data Float Delay		120		100	ns	
T_{RV}	$\overline{RD}$ Recovery Time	T_{CY}		T_{CY}		ns	

DATA BUS WRITE CYCLE

Symbol	Parameter	82720		82720-1		Units	Test Conditions
		Min.	Max.	Min.	Max.		
T_{AW}	A_0 Setup to $\overline{WR}$↓	0		0		ns	
T_{WA}	A_0 Hold after $\overline{WR}$↑	0		0		ns	
T_{WW}	$\overline{WR}$ Pulse Width	120		100		ns	
T_{DW}	Data Setup to $\overline{WR}$↑	100		80		ns	
T_{WD}	Data Hold after $\overline{WR}$↑	0		0		ns	
T_{RV}	$\overline{WR}$ Recovery Time	4 T_{CY}		4 T_{CY}		ns	

DISPLAY MEMORY TIMING

Symbol	Parameter	82720		82720-1		Units	Test Conditions
		Min.	Max.	Min.	Max.		
T_{CA}	Address/Data Delay from 2XCCLK↑	30	160	30	130	ns	CL=50pF
T_{AC}	Address/Data Float Time	30	160	30	130	ns	CL=50pF
T_{DC}	Data Setup to 2XCCLK↓	T_{IE}−20		T_{IE}−20		ns	
T_{CD}	Data Hold Time	0		0		ns	
T_{IE}	2XCCLK↓ to $\overline{DBIN}$		120		90	ns	CL=50pF
T_{CAH}	2XCCLK↑ to ALE↑	30	125	30	100	ns	CL=50pF
T_{CAL}	2XCCLK↓ to ALE↓	20	100	20	80	ns	CL=50pF
T_{AL}	ALE Low Time	T_{CY}+30		T_{CY}+30		ns	
T_{AH}	ALE High Time	⅓ T_{CY}		⅓ T_{CY}		ns	
T_{AV}	Address Valid Before ALE↓	30		30		ns	
T_{CO}	Video Signal Delay from 2XCCLK↑		150		120	ns	

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A.C. CHARACTERISTICS (Continued)

OTHER TIMING

Symbol	Parameter	82720		82720-1		Units	Test Conditions
		Min.	Max.	Min.	Max.		
T_{PC}	LPEN or VSYNC Input Setup to 2XCCLK↑	30		20		ns	
T_{PP}	LPEN or VSYNC Input Pulse Width	T_{CY}		T_{CY}		ns	

CLOCK TIMING

Symbol	Parameter	82720		82720-1		Units	Test Conditions
		Min.	Max.	Min.	Max.		
T_{CY}	Clock Period	250	2000	200	2000	ns	
T_{CH}	Clock High	105		80		ns	
T_{CL}	Clock Low	105		80		ns	
T_R	Rise Time		20		20	ns	
T_F	Fall Time		20		20	ns	

DMA TIMING

Symbol	Parameter	82720		82720-1		Units	Test Conditions
		Min.	Max.	Min.	Max.		
T_{ACC}	$\overline{DACK}$↓ Setup to $\overline{RD}$ or $\overline{WR}$	0		0		ns	
T_{CAC}	$\overline{RD}$ or $\overline{WR}$ Setup to $\overline{DACK}$↑	0		0		ns	
T_{RR1}	$\overline{RD}$ Pulse Width	$T_{RD1}+20$		$T_{RD1}+20$		ns	
T_{RD1}	$\overline{RD}$↓ to Data Out Delay		1.5 T_{CY} + 120		1.5 T_{CY} + 120	ns	CL=50pF
T_{KQ}	2XCCLK↑ to DRQ		45		40	ns	CL=50pF
T_{CQ}	$\overline{RD}$ or $\overline{WR}$↓ to DRQ↓		395		315	ns	

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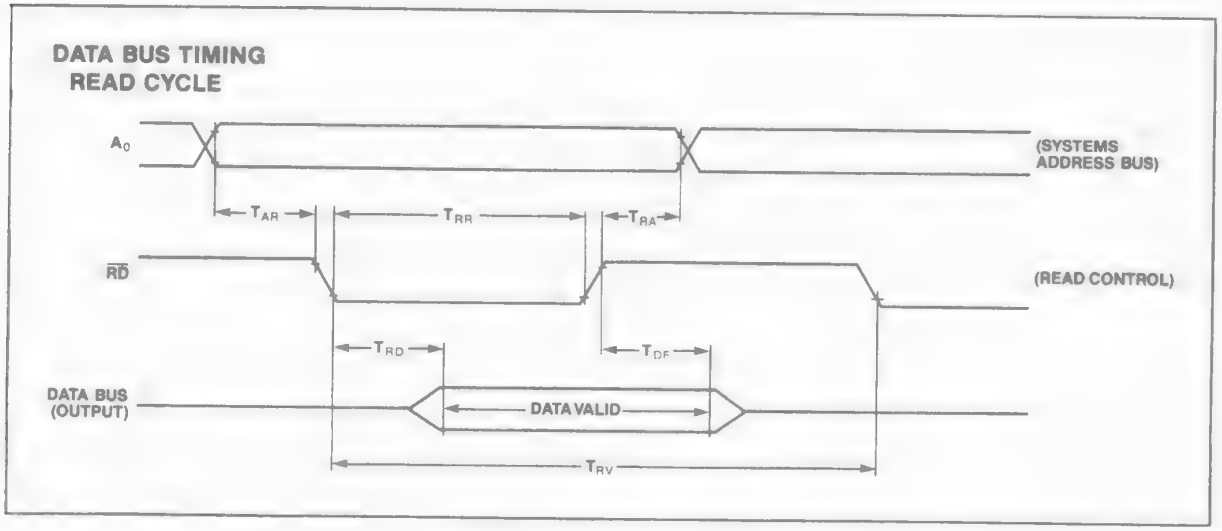
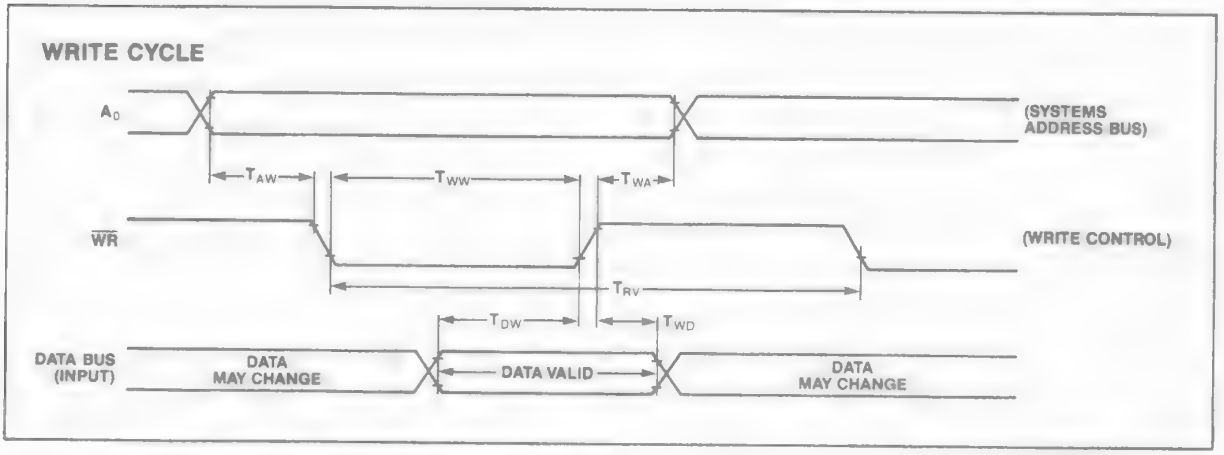
WAVEFORMS





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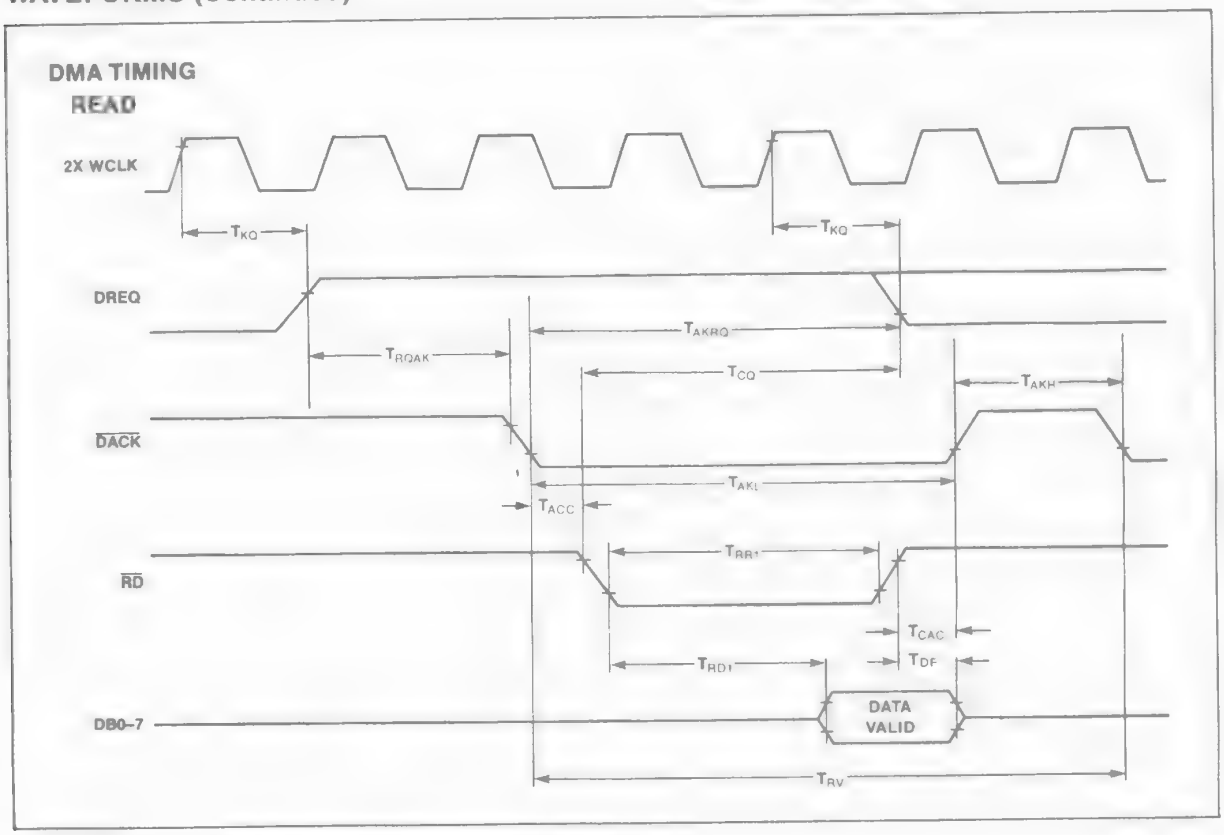
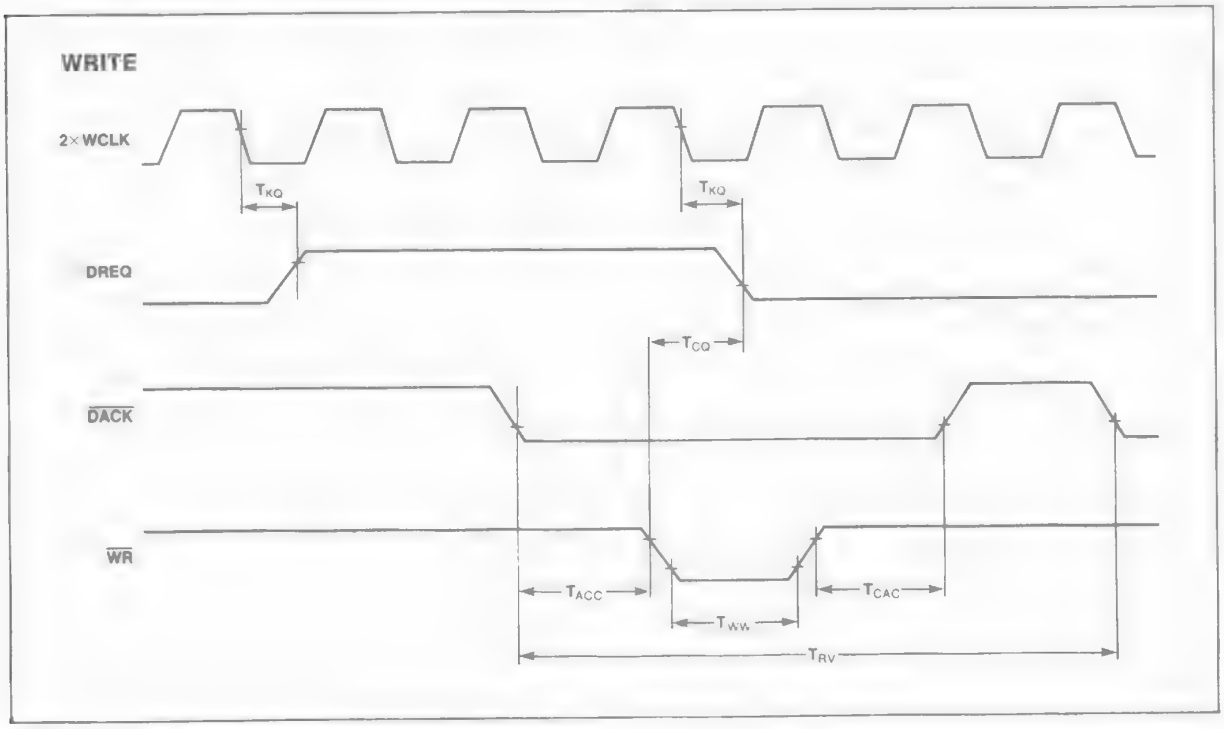
WAVEFORMS (Continued)





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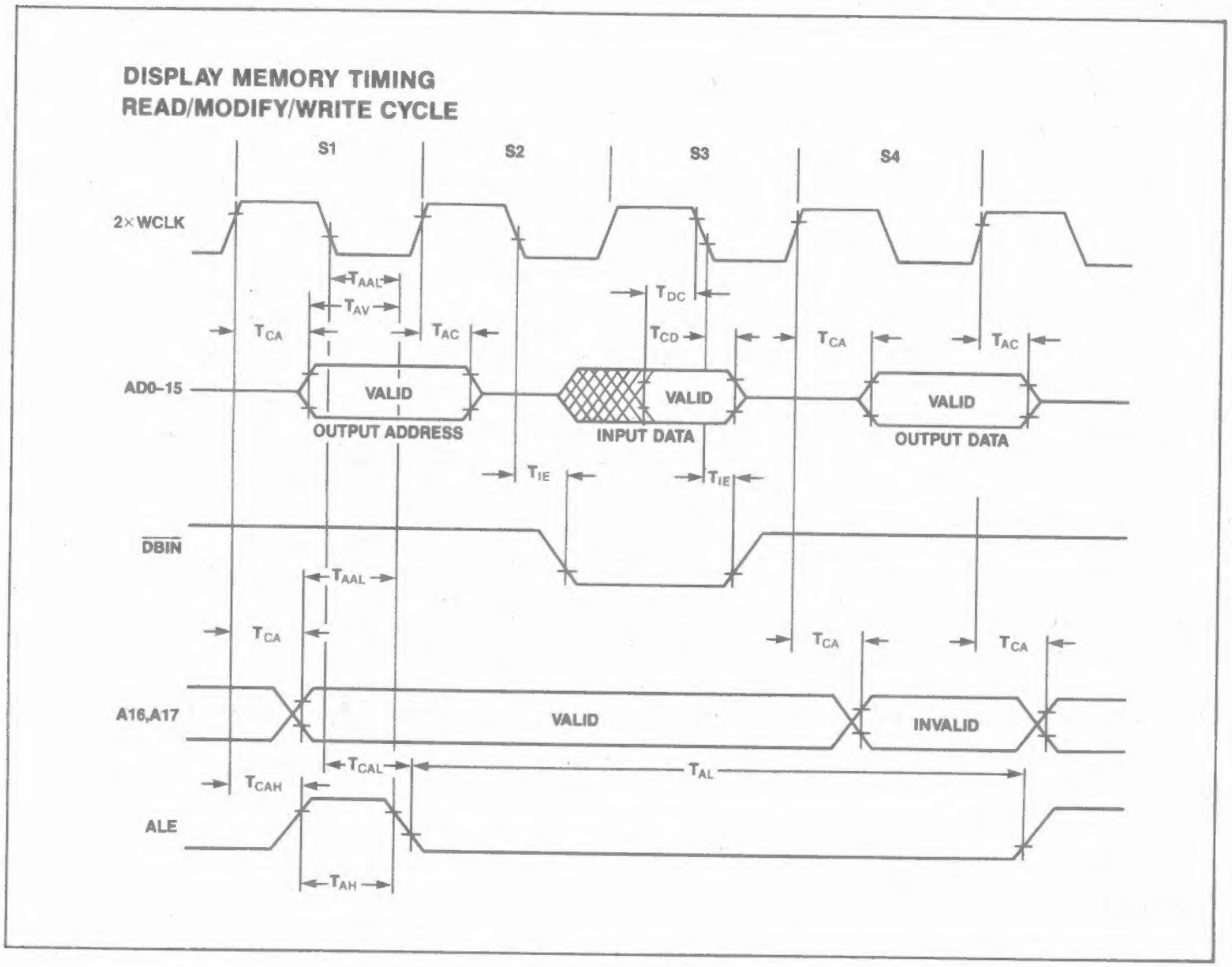
WAVEFORMS (Continued)



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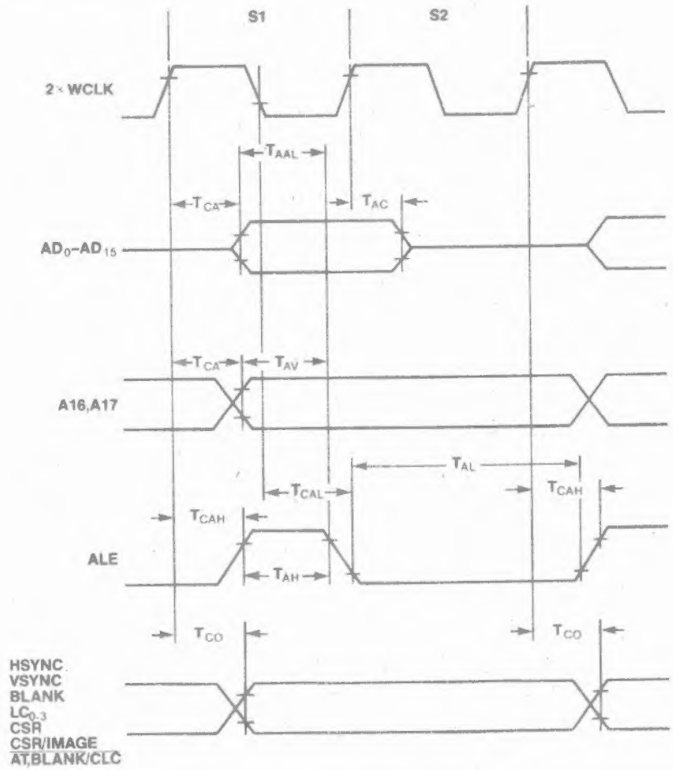
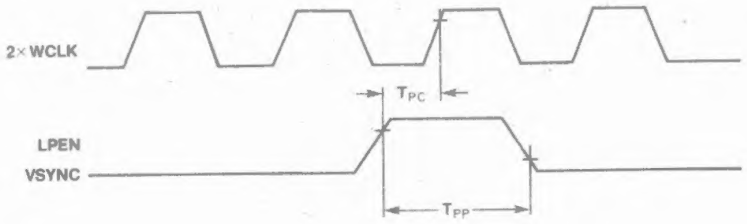
WAVEFORMS (Continued)

DISPLAY MEMORY TIMING (Continued)

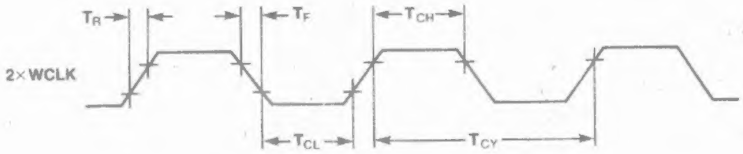
READ CYCLE



OTHER TIMING



CLOCK TIMING



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LITERATURE

1983 will be a year of transition for Intel's catalog program. In order to better serve you, our customers, we are reorganizing many of our catalogs to more completely reflect product groups.

In addition to the new product line handbooks listed below, an INTEL PRODUCT GUIDE (Order No. 210846) will be available free of charge in March. This GUIDE will contain a listing of Intel's complete product line along with information on quality/reliability, packaging and ordering, customer training classes and product services.

Consult the Intel Literature Guide (no charge, Order No. 210620) for a complete listing of Intel literature. Literature is presently available in other forms for those handbooks that will not be published until later in the year. Write or call the Intel Literature Department, 3065 Bowers Avenue, Santa Clara, CA 95051, (800) 538-1876, or (800) 672-1833 (California only).

HANDBOOKS

Memory Components Handbook (Order No. 210830)
Contains all application notes, article reprints, data sheets and other design information on RAMs, DRAMs, EPROMs, E^2PROMs, Bubble Memories.

Microcontroller Handbook (Available in May)
Contains all application notes, article reprints, data sheets, and other user information on the MCS-48, MCS-51 (8-bit) and the new MCS-96 (16-bit) product families.

Military Handbook (Order No. 210461)
Contains complete data sheets on all military products.

Microprocessor and Peripherals Handbook (Order No. 210844)
Contains data sheets on all microprocessors and peripherals. (Individual User Manuals are also available on the 8085, 8086, 8088, 186, 286, etc.)

Development Systems Handbook (Available in April)
Contains data sheets on development systems and supporting software.

OEM Systems Handbook (Available in May)
Contains all application notes, article reprints and data sheets for OEM boards and systems.

Software Handbook (Available in May)
Contains software product overview as well as data sheets for all Intel software.

Quality/Reliability Standards Handbook (Available in April)

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